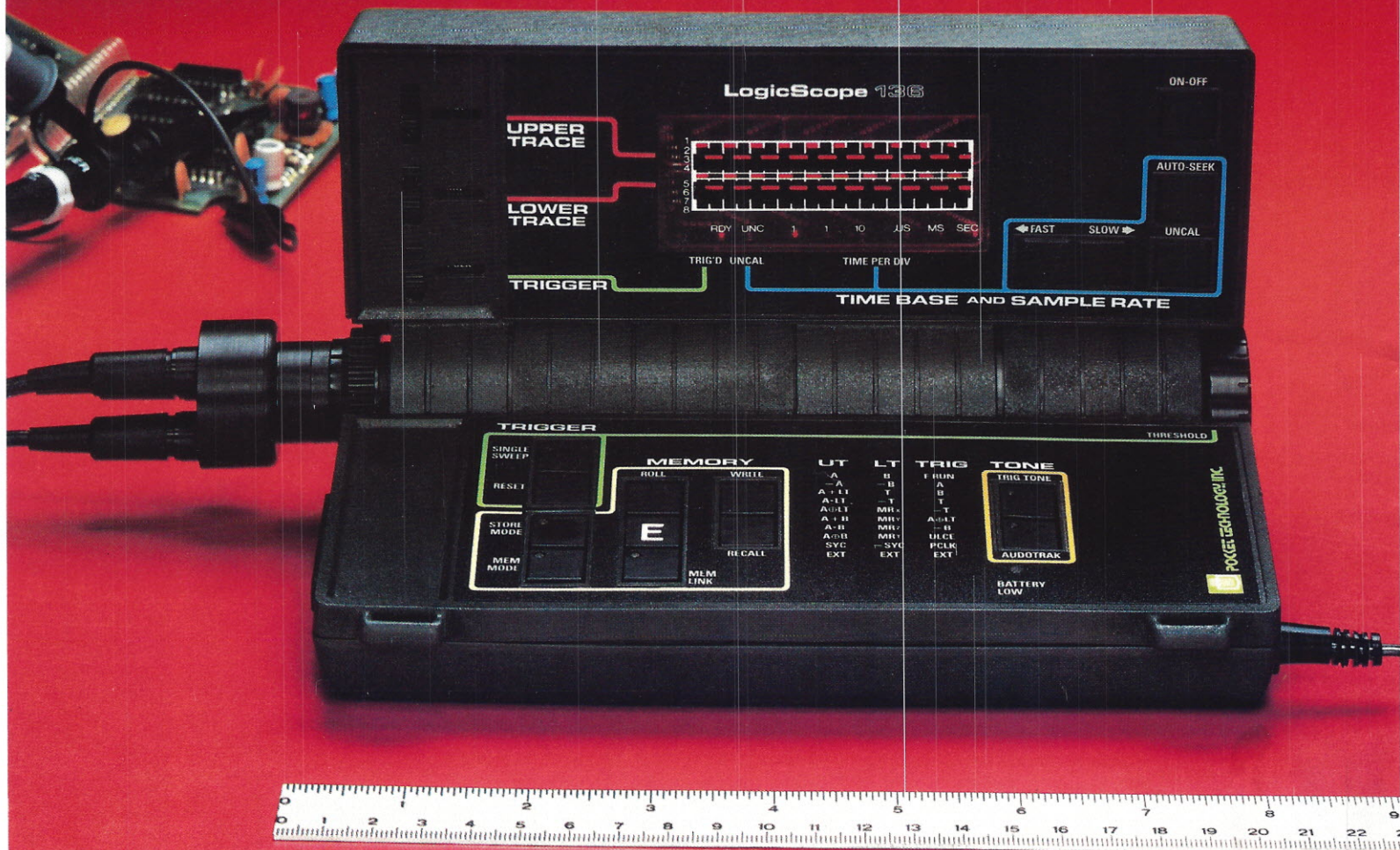


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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

OCTOBER 1984

VOL. 6 NO. 10

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by Raymond GA Cote

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About the cover: Creating an intelligent robot means more than just building a mechanical marvel and adding a powerful computer system. The most important part of any robot design is its ability to gather information from the surrounding world. Data acquisition systems provide the robot with information about its environs. This month's cover, by Robert Tinney, shows how an intelligent robot could be used to gather geological information from remote areas.

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Editorial

RATIONAL RELATIONS

BY RAYMOND GA COTE

Personal robots... is there a place for them in today's world? While one large portion of the populace seems to be running about worried that robots are taking over their jobs, another is claiming that the coming robot revolution is the solution to our economic problems, the greatest assist to the homeowner since the invention of the automatic washing machine, and the latest thing in electronic watchdogs.

Reality, of course, is somewhere between these two extremes. Before the personal robot finds a niche in the household, it must develop useful abilities. At present, these machines are little more than toys capable of running around and (perhaps) interacting with humans in a very limited manner. The point which cannot be overstressed is that a robot must *do something!* If it's unable to earn its keep it's not worth maintaining.

A continuing promise (it will be out in two months) from the robot manufacturers is for a personal robot with a vacuum attachment. Let's face it, folks, I can strap a vacuum cleaner to the back of my dog, but that doesn't mean my rugs are any cleaner. At present robots are a long way from learning how a room is laid out, finding all the dirt on the floor, moving the furniture to clean under it, and leaving the room the way they found it. Today's relatively tall robots just can't clean under the beds and dresser. If I spend \$3000 for a vacuum cleaner, I want it to clean corners.

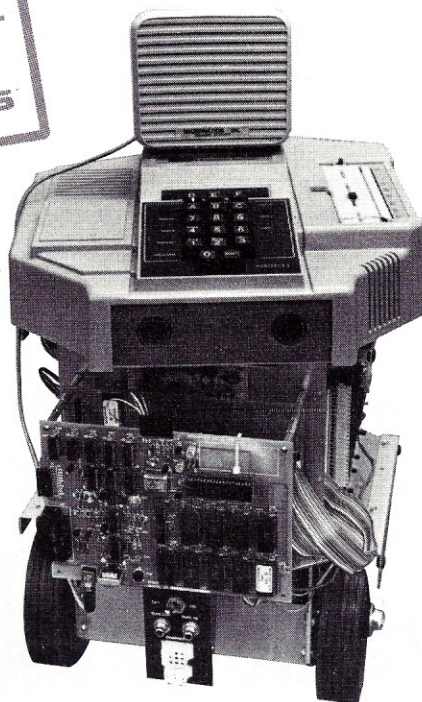
Some manufacturers seem to just insist on promising more than they can deliver in the near future. Many companies seem to be attempting to solve the general problem of an all-purpose robot. Current experience seems to show that the knowledge and computing power necessary to solve this problem is not yet available. When developing a product for market, the first step is to define the problem to be solved, and the market with that problem. At present, personal robots are being thrown at the marketplace in hopes that a need will arise.

The more reasonable approach to developing a product is to define a small, finite, understood problem and then solve it. This is slowly happening. Personal Robotics Corp. has produced a robot which may well be the first true show robot. It is designed to seek out people, attract them to a display at a show or in a store, and then talk to them about a product or activate an interactive display. The robot can recognize the words "yes" and "no" and change its actions accordingly. Although this is a very limited, specialized purpose, it is also a purpose that a robot salesman can define, and announce: "This is what my robot does."

The most important point is that robots must fit in with our notion of reality. If robots don't fit into the needs and desires of our lifestyles, we won't use them. Remember what happened with computers when you were always being told, "It has to be done this way, it's on the computer." Tools, of which computers and robots are only two examples, must be made to fit into our everyday lives. They should not force us into drastic changes. It is only when robots develop rational relationships with reality that they will be widely, and gladly, accepted as useful tools.

Circle 19

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Calendar

October

2-4 October. 14th International Symposium on Industrial Robots. Gothenburg, Sweden. Contact: Swedish Trade Office, 4000 Town Center, Suite 202, Southfield, MI 48075, telephone (313) 352-6990.

Nearly 1,000 delegates are expected to participate in this year's symposium. In connection with the symposium, there will also be an extensive international exhibition showing the latest developments and achievements in the field of industrial robots.

2-4 October. AUTOFACT 6. Anaheim Convention Center, Anaheim, CA. Contact: Gregg Balko, Computer and Automated Systems Association of SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

AUTOFACT 6 will feature a comprehensive program of tutorials and conference sessions covering the entire spectrum of computer-integrated manufacturing—from design and engineering, through fabrication, assembly, inspection and testing, to shipping.

2-5 October. Robot 84, Scanautomatic 84, and The 14th International Symposium on Industrial Robots. Gothenburg, Sweden. Contact: Swedish Trade Fairs Foundation, Box 5222, S-402 24 Goteborg, SWEDEN, telephone 46 31 20 00 00.

Three major international events devoted to the design, production, and uses of industrial robots will take place in the Swedish Trade Fair halls simultaneously in October. Robot 84 is an international exhibition of industrial robots and control systems for materials handling, assembly, and complex production tasks. Scanautomatic 84 covers industrial computers and the pneumatic, hydraulic, and electronic components which provide the backup technology for industrial automation. The Symposium on Industrial Robots is organized jointly by the Swedish Trade Council, the Swedish Trade Fairs Foundation, and MEKAN, Sweden's largest industrial association.

ACM-84, The Fifth Generation Challenge. San Francisco Hilton, San Francisco, CA. Contact: ACM-84, PO Box 32575, San Jose, CA 95152, telephone (415) 948-6306.

The Japanese Fifth Generation supercomputers pose a challenge to American computer manufacturers. The ACM-84 Conference topic areas attest to the concern about the Japanese challenge: supercomputers; developments in artificial intelligence; robotics and sensing; the impact of the fifth generation; limits on technology transfer; applications for the 1990s in business, education, manufacturing, research, and the professions; and anticipated changes in society.

10-12 October. InteRobot-West '84. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

InteRobot-West '84 offers 20 technical conference sessions, three special-interest tutorials, and 80 internationally recognized speakers and session chairmen. Session titles include: *Industry Overview; Tooling Design; Machine Languages; Machine Vision; Machine Sensors; Robots in the Foundry; Personal and Educational Robots; Education in Robotics; and Emerging Robot Applications.*

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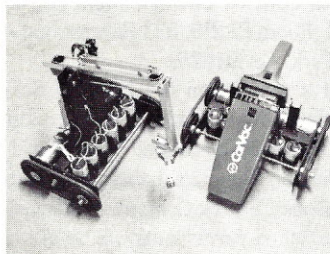
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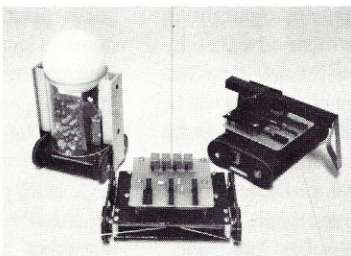
ARM ADD ON UNIT (see ROBOT IV) Allows mobile robot to pick up objects. KIT \$150. ASSY \$250.

KITTEN MINI ROVER A smaller, 6" system, includes same 7 channel RC, motor controller and computer interface. KIT \$200. ASSY \$330.

MINI ARM (the cats paw) adds pick up action. KIT \$60. ASSY \$100.

RUG RAT (R2 micro rover) slightly smaller. KIT \$200. ASSY \$330.

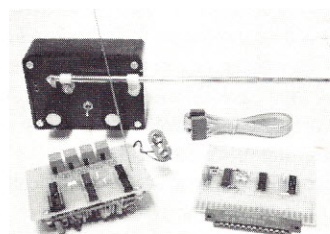
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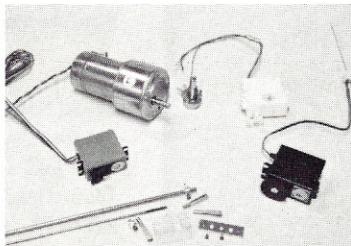
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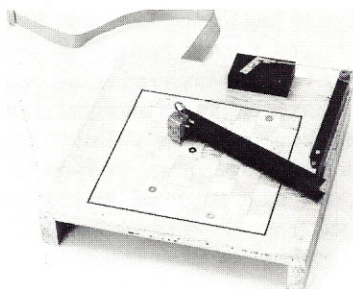
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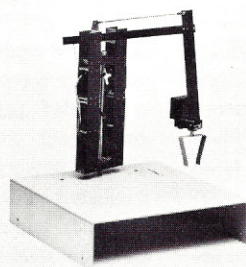
ROBOT I Two axis robot arm. Can draw, pick up game markers, etc. A good introduction to coordinate transformations, teach mode and direct programming, and robotic hardware. KIT \$125. ASSY \$210

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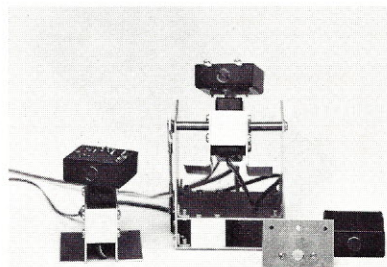
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Calendar

13-15 October. Mechatronics—The Usage of Automation in Today's Manufacturing. Westin Bonaventure Hotel, Los Angeles, CA. Contact: Patti Hirahara, Japan Trade Center (JETRO), 555 South Flower St, Los Angeles, CA 90071, telephone (213) 626-5700.

A half-day seminar featuring Dr. Makoto Kimura, Deputy Director General of the Ministry of International Trade and Industry's Mechanical Engineering Lab, Koya Kimura, Director and General Manager of Toshiba Machine Co., Ltd's Engineering Lab, and Dr. Ichiro Miwa, a member of the Board of Directors of Hitachi Medical Corporation's Machinery, Engineering, and Manufacturing Division. The Japanese representatives will present discussions on the use of mechatronics in today's industry, applying mechatronics to the manufacturing process, and applying mechatronics technology to consumer goods.

25-27 October. Robotics Seminar. IIE Education Center, Technology Park/Atlanta, Norcross, GA. Contact: Institute of Industrial Engineers, Conference Department, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

The Robotics Seminar is designed to acquaint participants with the variety of equip-

ment available and how and where robots might be used effectively. Special seminar features include a full-day laboratory experience where participants can see robots in action, and a workshop session for discussing and analyzing potential robot applications.

November

4-9 November. Intelligent Robots and Computer Vision. Hyatt Regency, Cambridge, MA. Contact: SPIE—The International Society for Optical Engineering, Bellingham, WA 98227-0010, telephone (206) 676-3290.

The emphasis for the 1984 conference is intelligent robots, vision, and sensor systems. The intent of the sessions is to address and interchange ideas on a wide range of applications, issues, and techniques for these advanced intelligent systems. State-of-the-art technical design and modern equipment concepts will be presented. Topics to be addressed and for which contributed papers are requested include: government and industrial programs in intelligent sensors and robotics; applications of intelligent sensor systems; statics, kinematics, dynamics, and control of robot systems; standards for sensors and robots; image process-

ing; feature extraction; three-dimensional object representation; use and application of artificial intelligence; and image understanding in intelligent robotics and computer vision.

13-14 November. Intelligent Robots: Achievements and Issues. SRI International, Menlo Park, CA. Contact: Cherry Powers, SRI International, Room EL219, 333 Ravenswood Ave., Menlo Park, CA 94025.

Under a grant from the National Science Foundation, SRI International will conduct a two-day workshop co-chaired by Dr. David Nit-zan, Director, Robotics Laboratory, and Dr. Robert Bolles, Senior Computer Scientist. Up to 50 workshop participants will be invited to discuss significant achievements and issues in seven principal areas of robotics research: mobility, manipulation, noncontact sensing, contact sensing, adaptive control, off-line programming and planning, and robotic CAD/CAM system integration. In addition, up to 150 people from academic, industrial, and government organizations will be able to attend the workshop as observers and participate in two open-discussion sessions.

13-15 November. Man or Machine—A Choice of Intelligence. Sheraton Sand Key Hotel, Clearwater Beach, FL. Contact: Rhonda Gerganess, CAM-I, 611 Ryan Plaza Drive, Suite 1107, Arlington, TX 76011.

Decision processing methods and their application will be the theme of CAM-I's fall conference. The conference will address a number of issues that have developed during CAM-I research projects. In particular, the issue of what type of decision process should be used for particular projects will be discussed. Indications are that there is no one system that meets all requirements. Some situations are best served by Decision Trees while others by Expert Systems or true Artificial Intelligence methods. Although the conference will attempt to make distinctions between the different methods, the purpose is not to create rigid definitions of decision processing methods.

27-30 November. Robots-West. Anaheim Convention Center, Anaheim, CA. Contact: Jeff Burnstein, Robot Institute of America, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-0778.

Robots-West is RIA's first regional show. It will feature exhibits by leading robot manufacturers and component suppliers. Approximately 6,000 visitors are expected to attend the three-day exposition and conference.

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MODULAR COMPONENTS AND CONTROLS FOR THE ROBOTICS INDUSTRY

Sensory Perceptions

by Ray Cote

HERO PATROL. HERO Patrol by Robotronix of Los Alamos, NM, turns your HERO 1 robot into a watchful patrol robot. HERO 1 can wander from guard post to guard post looking for intruders. The program is distributed on cassette which can be loaded directly into the HERO 1. Patrol programs are entered using the hexadecimal keyboard. Patrol commands include dead reckoning, turning, turning around, changing sides (of a hallway), standing guard, repeating a series of instructions, or stopping. Several simple program editing commands are also provided.

HERO Patrol commands allow the HERO 1 to follow walls or dead reckon across open spaces. Due to cumulative inaccuracies, the Patrol manual suggests you use the dead reckoning option as little as possible. Most of the HERO Patrol commands assume that HERO 1 is moving along a wall. The normal mode of operation is to have HERO move along a wall until a specific spot is reached, at which point HERO goes into guard mode. Guard

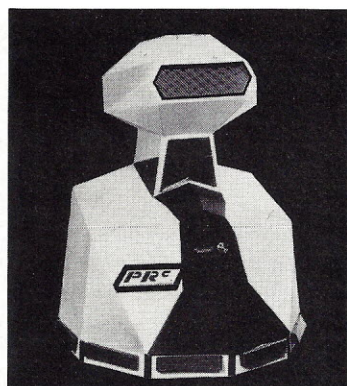
mode first registers the current light and sound levels. If the light or sound levels change (within a preset sensitivity range) HERO 1 interprets this as an intrusion. The motion detector can also be used to detect intrusions. Intrusions (up to 16) are recorded for playback later. When an intruder is detected, the event, and what triggered the intrusion, are remembered. HERO 1 can then perform one of three actions: stand quietly and hope no one notices, raise a ruckus, or take evasive actions. You can determine which action HERO takes during an intrusion.

An interesting example provided with the User's Guide shows how to make HERO run away and hide (brave robot that it is). After all, considering how valuable HERO is, you don't want some intruder carrying it off. (I wonder how Asimov's Three Laws of Robotics apply?)

The program is fun to use, although having to write programs with the hexadecimal keyboard is always time-consuming. The built-in HERO Patrol editing commands do decrease the amount of time spent re-entering informa-

tion. Anyone looking for a program to demonstrate a robot's capabilities will find HERO Patrol very useful.

KNOWLEDGE ENGINEERING TOOL. M.1 is a software tool for exploring practical applications of knowledge engineering. Developed by Teknowledge, Inc., M.1 is used to design, build, and run standalone knowledge systems that solve problems normally requiring human intelligence. M.1 runs on the IBM Personal Computer and offers many capabilities previously found only on larger systems. System developers create knowledge systems by building a knowledge base in a special English-like language. After the knowledge base is constructed, M.1 engages the developer in a question-and-answer consultation about a specific problem. M.1 uses the knowledge base to reason about the problem in order to make a recommendation or draw a conclusion. Advanced knowledge engineering features include an English-like knowledge-representation language, an interactive knowledge-base debugging system, explana-

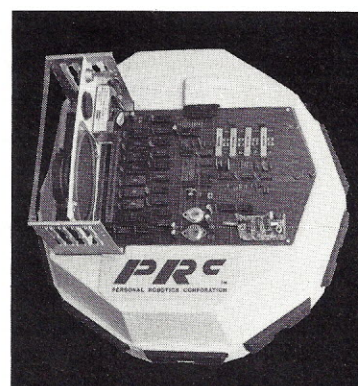


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tion facilities for justifying M.I. conclusions, and certainty factors.

Although M.I. is specifically designed as an evaluation tool for knowledge-engineering concepts, it should be quite usable for many smaller knowledge database applications.

MICROMATION NOW ARCTEC. Columbia, Maryland-based Micromation, Inc. has become a division of Arctec Group, Inc. (AGI) and changed its name to Arctec Systems. The new division will assume manufacturing responsibilities for most electronic and instrumentation products of the seven AGI divisions. Arctec Systems designs, manufactures, and markets voice recognition and other products for personal robots and microcomputers, and data acquisition systems for arctic and offshore environments.

AUTOMATION IMPACT. The Congressional Office of Technology Assessment has released its final report on CAD/CAM called "Computerized Manufacturing Automation." The OTA

report challenges some of today's conventional wisdom about the effect of advanced automation on employment, education, and the workplace. According to the report, large-scale unemployment due to advanced automation systems such as computer-aided design, robots, computer-numerical control machines, and flexible manufacturing systems will not occur before the year 2000.

Interestingly, the report attributes the gradual effect to schools' inability to provide enough technically competent people to plan, install, and maintain integrated advanced automation systems. Consequently, the systems will not achieve their full potential productivity.

RB5X DEVELOPMENTS. While still attempting to reorganize under Chapter 11 bankruptcy laws, RB Robot Corporation has reached an agreement with Robotics International to form a limited partnership for the development and marketing of an obstacle avoidance sensor system for personal robots. Michigan Robotics of Jackson, Michigan will be the general part-

ner for this project.

The proposed obstacle avoidance sensor system is composed mainly of ultrasonic and infrared sensors, which will provide RB Robot's RB5X with the ability to detect stairways or other dangerous drop-offs. This system will also enable RB5X to detect, with considerable reliability, objects in its immediate vicinity.

ROBOCAM VISION. Robocam™ from Silma, Inc. provides a computer-aided engineering workstation for online and offline programming of industrial robots, and simulating robots and their workcells. The system, based on an Apollo Domain computer system, allows robot commands to be entered interactively and the resulting motions viewed as a graphics simulation. Arbitrarily complex application programs can be built up by iteration from simpler ones. Robot programs are developed in RISE™, an arm-independent robot programming language. RISE allows programmers to use many different geometric representations for arm position and orientation, general operators for translation

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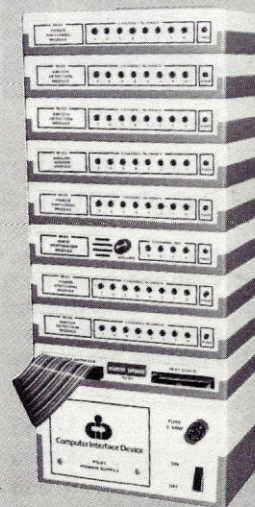
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Aimed at the engineering and computer professional, this book combines electronics and mechanical engineering topics to provide a practical introduction to the basic principles and concepts of robotics. Numerous mathematical models, diagrams, and appendices illustrate typical robot design considerations along with individual components such as controls, motors, actuators, and sensors. Emphasizing applied concepts as well as theoretical, the book also includes chapters on the computer control, characteristic properties, usage, "training," and real-world applications of robots. 6 1/2 x 9 1/4 208 pp. 60 illus. **\$29.95**

Robotics Research: The First International Symposium

Edited by Michael Brady and Richard Paul

The fifty-three contributions collected in this book present leading current research in one of the fastest moving fields of artificial intelligence. Organized around a view of robotics as "the intelligent connection of perception to action," they convey the excitement of cross-disciplinary discussion by scholars from the United States, Japan, France, the United Kingdom, West Germany, and Australia. Chapters in the book's first part explore the connection between perception and action in three sections that deal with task level programming, integrated systems, and walking machines. The second part reports recent progress on the perceptual basis of robotics, with chapters grouped in sections on visual inspection, three-dimensional vision, and (nonvisual) local sensing. The third part focuses on systems that facilitate action, with sections that discuss mechanisms, kinematics and dynamics, and feedback control. A final part considers the application of robot systems to manufacturing, with chapters divided into two sections: on systems for manufacture and on robots and manufacture. The editors have written introductions to each of the book's four major parts and eleven sections.

This book is the twelfth in the MIT Press Series in Artificial Intelligence, edited by Patrick Henry Winston and Michael Brady. 7 x 10, 1000 pp., 600 illus. **\$65.00**

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Numerous examples of both APT and COMPTACT II part programming provide a firm basis for more advanced programming courses for students. 1982, 300 pp., illus., **\$24.95**

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The 1984 S. Klein Directory of COMPUTER GRAPHICS SUPPLIERS Hardware, Software, Systems and Services

This latest edition identifies more than 500 supply sources. Directory entries provide basic product information and business background on each company, including ownership, top management, company size, sales volume, and year of origin as well as address, phone number, telex or TWX, and persons to contact. The Directory also features a computer generated, cross-index that enables readers to identify vendors by applications of interest and by specific technology. In addition, you also get a 5-page briefing, prepared by Carl Machover, industry consultant, on the considerations and tradeoffs to be made when buying computer graphics products. 224 pp. **\$60.00**

Industrial Robotics Handbook

By V. Daniel Hunt

In one comprehensive volume, this extensively illustrated handbook provides a unique overview of the subject of robotics, its hardware, various types, their functions and future in industry. All of the information presented has been obtained from a wide variety of knowledgeable sources in the field including the most recent research available. An extensive selection of photographs, diagrams, and charts amplify the text.

Hunt reveals a wealth of information on foreign research and development in the industry and the companies involved in and exploring the manufacture of industrial robots. He also supplies an extensive list of the various robotic systems, including the potential of "smart robots," grouped into types of models. The list includes important technical information on specific applications pertaining to: tolerances, load carrying capacities, price, and names and addresses of companies and individuals to contact for further information.

1983, 352 pp. (T), illus. **\$32.50 (T)**
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It is without a doubt the most complete work available on control of robot arms and manipulators and will be a guide and valuable reference work for many years to come.

Published by M.I.T. Press, 279 pages Price: **\$79.95**

Robot Motion: Planning and Control

Edited by Michael Brady, John Hollerbach, Timothy L.

Johnson, Tomaz Lozano-Perez and Matthew T. Mason. This major work is geared to the development of robotics. In an effort to aid senior and graduate-level students in the field, the editors have grouped the book into five main chapters: Dynamics; Trajectory Planning; Feedback Control; Compliance and Force Control and Spatial Planning.

What makes this book "unique" is that each chapter is introduced by a substantial analytical survey that lays out the problems in that area of robotics and the approaches and solutions that have been tried, with an evaluation of their strengths and shortcomings. There is even an overall view in the development of artificial intelligence. This book is a "must" for anyone interested in the robotics field.

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Robocam is part of Silma's SILCAM, claimed to be the first truly three-dimensional vision system capable of extracting three-dimensional information from television pictures.

SHUTTLE CONSTRUCTORS. NASA is planning to use robot welding and vision systems to construct Space Shuttle engines. A contract has been released to Advanced Robotics Corp. for their Cyro 750 robotic work cell, in conjunction with a newly-developed vision system from Ohio State University. Professor Richard Richardson of Ohio State University has developed a vision system which uses a camera to view the molten weld puddle by looking through the weld torch barrel. This image can be used to determine the weld seam position. In addition, the size and shape of the robot can be monitored to vary welding process parameters.

MECHANICAL COCKROACHS? The Ilme-

nau College of Technology in the German Democratic Republic is studying the simply structured nervous system of the cockroach to perfect sensor-controlled robots. The knowledge gained will be used for circuit drawings that improve the self-regulation action of robots exposed to stimuli from the environment. The decision to study these insects is based on the fact that the nervous systems in living organisms are control and regulation devices that enable organisms to react rapidly to environmental changes. The cockroach is ideal for the study because of its ability to recognize and analyze possible danger within a matter of milliseconds.

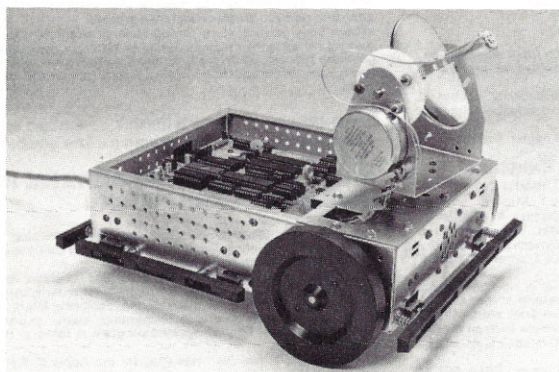
The study is being conducted microscopically with special electrodes connected to the cockroaches' nerve cords. The insects are subjected to stimuli to allow measurement of time and intensity of reaction, tracing of the information path through the nervous system, and reconstruction of the information coordination process.

Preliminary results have already shown that about 400 cockroach nerve fibers are "wired"

with each other in a ganglion, from which only 14 neural canals continue. This principle of nerve building was found to be the same through all the higher stages of information processing up to the nerve center of the cockroach. However, some computations and decisions concerning response to the environment are already made in the first ganglion. It is only when the stimulus reaches a certain strength that the next processing stage is activated.

WALK RIGHT IN. Odetics, Inc has received a contract from the Electric Power Research Institute (EPRI) to study how mobile robots with advanced performance characteristics could be used in nuclear power plants. Odetics will investigate a number of maintenance tasks currently being conducted at nuclear power plants by humans. Performance of these tasks can incur extraordinary expense due to radiation protection procedures and plant downtime. Odetics will recommend a set of tasks and work areas where manpower and resulting expenses can be reduced using a mobile robot.

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pany profiles by sensor type. You'll find information on who makes nearly 100 different classes of sensors ranging from accelerometers to thermocouples, from gas pressure to humidity, from acidity to resistance. If a physical, chemical or biological quantity can be readily turned into an electronic signal that can be analyzed, you'll find a pointer to the manufacturer of such a sensor/transducer product. For each type of sensor, you'll find an alphabetical listing of company names and page numbers, giving you fast access to the suppliers of each type of sensor.

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INTRODUCTION TO DATA ACQUISITION

Joseph Hadzima, Applications Engineer
Taurus Computer Products, Inc.
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The flood of low-cost personal computers into the lab and industrial environments has given engineers and scientists the flexibility, power, and efficiency of computerized data acquisition and control. Personal computers provide large amounts of computational power and quality graphics at low cost. Most importantly, these systems are easily programmed. Unique, efficient solutions can be quickly created for particular applications. Personal computers invite innovation. This type of innovation has already created a revolution in the office and is about to do the same to the factory and laboratory.

With this flood of computer power and inexpensive data acquisition systems comes a host of new terms and definitions. This article provides an introduction to data acquisition techniques, shows how various transducers and sensors can be monitored and controlled, and explains some of the terminology.

DEFINITIONS

First, since the topic under discussion is computer-automated systems, let's define what the term means. *Automation* is a controlled process in which all the process variables act in a desired manner at the proper time. An example is a bottle-filling station at your favorite brewery. A tap discharges 12 oz. of beer into each bottle. Another machine then caps each bottle. Obviously, you don't want to discharge beer from the tap unless a bottle is underneath. Nor does it make sense to cap an empty bottle. To create a useful system, the desired processes must not only work, they must operate at the proper time.

The advantages provided by automation fall into four major groups:

- Increased Accuracy

- Increased Precision
- Increased Productivity
- Lower Overhead Costs

The first two advantages are an increase in the accuracy and precision with which products are created and information is tracked. The terms accuracy and precision are often misinterpreted as meaning the same. Accuracy and precision are terms which help to qualify a system's measuring abilities. All measurements are relative to another measurement. Each measured value is always compared to a standard, or true, value. As an example, consider how you would determine the amount of carpet needed for your livingroom floor. You can not simply ask a salesperson for "one square livingroom of carpet" because livingrooms are not a standard measurement. The accepted measurement is square yards. You can compute the livingroom area with the accepted measure of square yards.

The *range* of values between the measured value and the true (standard) value defines measuring device's accuracy. *Precision* is a measure of the spread of values in a series of measurements of the same value. Figure 1 demonstrates the difference between accuracy and precision.

Precision is often called repeatability. If you were to measure the length of a pencil on your desk with a steel rule marked in millimeters, that device would be accurate to the width of one mark, and have a precision to one millimeter. Since steel expands and contracts in relation to temperature, the accuracy of the rule changes as the room temperature does. However, the rule is still precise to one-tenth of a centimeter. If you measure the pencil 100 times on a hot summer day, you should get the same value each time. However, the accuracy of the instrument (rule)

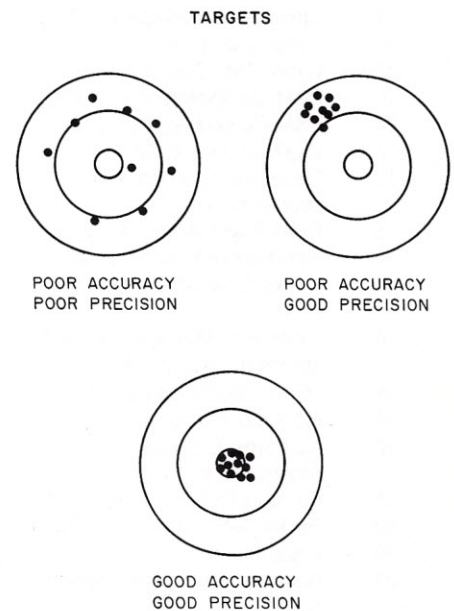


Figure 1. A graphic representation of the difference between accuracy and precision. Accuracy is the ability to make a measurement and actually determine the correct value. Precision is the ability to repeat the same measurement several times and always get the same answer.

has changed from when you used it in your nice cool office.

The third automation advantage is increased productivity. It's easy to demonstrate how automation can increase productivity. Consider a scientist using a strip-chart recorder to monitor values from an experiment. At the conclusion of the experiment, all the data from the stripchart must be read and entered by hand into a computer for analysis. This process could take hours or weeks depending on the amount of data. The amount of time needed to enter the data before analysis is time wasted, since the data analysis cannot be started, nor can another experiment be set up, based on the results from the first experiment. An automated system can re-

duce the amount of time that elapses between the end of an experiment and the start of data analysis by loading the data into the lab computer while the experiment is taking place. Automated data recording also removes the possibility of transcription errors since the measured values are the recorded values.

CONTROL

Effective control techniques are at the heart of any automation system. In addition, you must also be able to monitor or acquire data about a process before making intelligent control decisions. For example, in the beer bottling plant, you must monitor the position of empty bottles in relation to the tap. The decision to discharge or not to discharge beer from the tap is made after the bottle position data has been determined. Data acquisition can be considered as the heart of any control system.

Figure 2 shows three common types of control: open loop, closed loop with feedback, and feed forward. A common example of *open loop* control is cooking with an inexpensive microwave oven. You would place a chicken in the oven, set the timer, and hope for the best. The second type of control, *closed loop* or *feedback* control, takes some of the guesswork out of the cooking. While cooking the same chicken using feedback control, the process would include placing a temperature probe into the chicken. The probe allows the microwave oven to monitor the temperature and turn itself off when the chicken is cooked.

Closed loop control received its name because of the loop through which acquired data and control data pass. The controller monitors any deviation from the desired temperature value (set point). This is called the *error signal*. The error signal is used to compute a control signal called a *correction signal*. The correction signal is used by all control systems to force the process to reduce the error signal to zero.

Feed forward control is a form of closed loop control. Like open loop control, feed forward control predicts how the process will react. It is normally used when it is impossible to monitor the process or when the response time to the correction signal is very long. Feed forward control examines the input to a process, measures the disturbance to the process, and then uses this data to predict the necessary correction

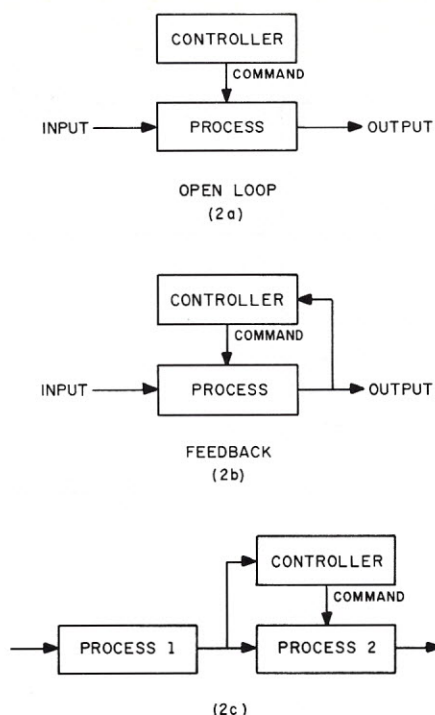


Figure 2. Three common types of control system are open loop, closed loop, and feed forward. Open loop control assumes the process being controlled is responding as predicted to the given inputs and commands. The controller has no knowledge as to whether the system is responding as expected. Closed loop control provides feedback information which tells the controller how the system is responding. The controller can then make decisions based on this information. Feed forward control monitors the inputs to a process, predicts the process' reaction to the input, and then computes a correction signal. This type of control is typically used when the response time to the correction signal is very long or impossible to monitor.

signal. Unlike open loop control, feed forward constantly monitors the system for disturbances. This type of control quickly becomes very complex since the ideal predictive controller must consider all possible disturbances to a process.

The next few examples of control techniques demonstrate the most common control type, feedback control. The first example of feedback control is called *dual position*, or bang-bang, control. A common example is the average home thermostat. The thermostat monitors room temperature and turns the heating system on or off depending on room temperature. Typically, there is a range of values above and below the set point (called the dead band) which will not cause the controller to switch states when the error is close to the set point. This allowable error saves wear and tear on the system since the system is not continually turning on and off. The dead band is normally between 0.5

percent and 20 percent of the normal operating range.

Another common closed-loop control technique is called *PID*. PID is actually three methods rolled into one: proportional, integral, and derivative. A *proportional* controller generates a correction signal proportional to the error signal. Proportional controllers respond to large errors with large correction signals, and to small errors with small correction signals. One of the problems with straight proportional control is that it can never bring the system exactly to the set point. The current measurements of the process (variable) are always offset from the ideal (set point).

The offset error caused by pure proportional control is often minimized by adding *integral* control. Integral control action integrates the offset error over time, and adjusts the correction signal to bring the process to set point. Since the correction signal is based on the history of the error signal, integral control can cause the process to oscillate about the set point. Therefore, although the averaged offset error may equal zero over time, oscillations appear in the trends. These oscillations can be offset by the use of derivative control.

Unlike integral control, *derivative* control responds to changes in the error signal, not steady-state errors. Derivative control reacts quickly to the constantly changing error signal produced by integral control and any sudden upsets to the system.

PID control is summarized in Figure 3. Proportional control does most of the work, and is often all that is required, but does yield an offset error. Integral control minimizes errors where proportional control becomes ineffective, but may encourage oscillation. Derivative control acts rapidly to head off trends in the error. However, it can make the process appear jerky and unstable. All three working together provide a responsive and smoothly operating system.

AUTOMATED INSTRUMENTS

Even this cursory look at several types of control and associated feedback techniques shows that there is often quite a bit of mathematics associated with process control. To create a laboratory or industrial automation system, you should start with intelligent machines. The advantage of intelligent machines is flexibility and the

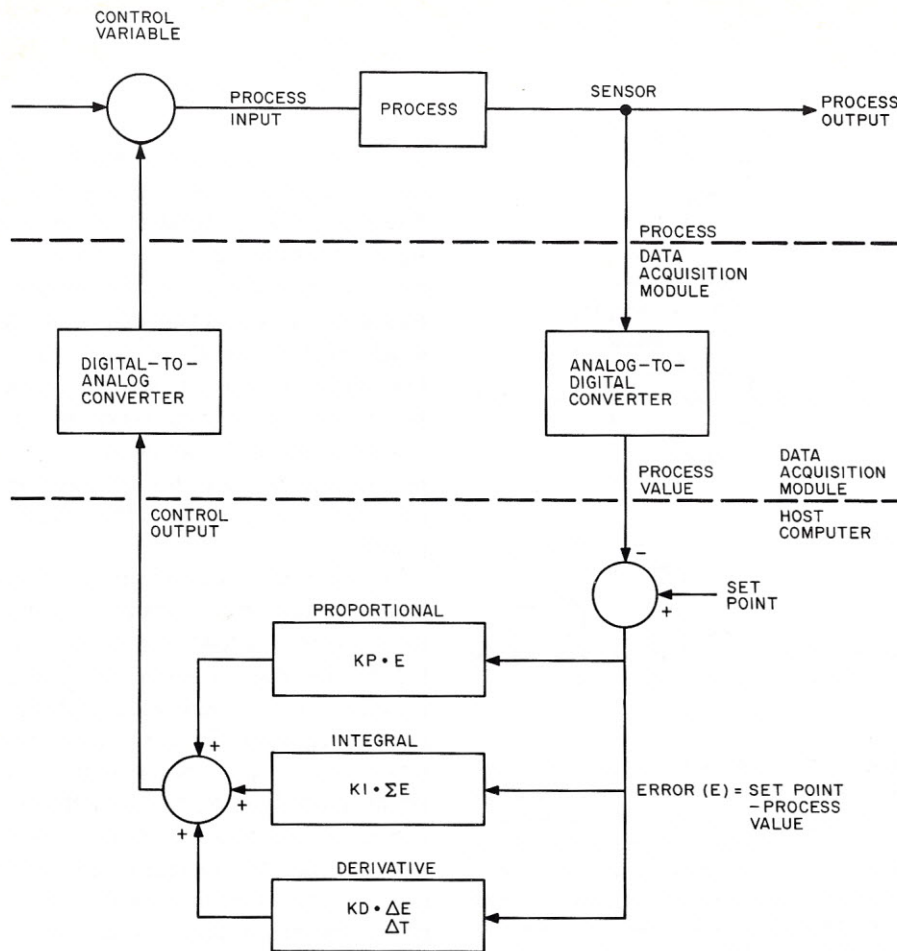


Figure 3. A proportional-integral-derivative (PID) feedback control system. This feedback technique combines three feedback systems to control the process and compensate for each system's potential weaknesses.

ability to really modify various control algorithms. Laboratories are prime candidates for flexible automation equipment. Once experimental data has been analyzed major changes to the experimental process may be required. A flexible environment allows the researcher to rapidly modify the equipment for the next experiment.

Standard personal computers provide a good foundation for a general-purpose data acquisition and process control system. Standard equipment eases program development since commercial data analysis software is often readily available. Since the trend in personal computers is toward more powerful and less expensive systems, you should not rely on any one personal computer but allow your system to grow with the latest and greatest hardware. One way to ensure you can easily upgrade your data acquisition system is to divide the system into two parts: the personal computer controller, and an intelligent front end which will interface the real-world signals (temperature, pressure, flow, voltage, etc.) to the host. If the front

end must connect to a variety of personal computers, it must use a standard communications protocol such as RS-232, RS-422, or IEE-488. The front end must also be expandable to meet future requirements, be easily programmable, and above all else, handle the necessary real-world signals.

REAL-WORLD SIGNALS

Table 1 shows some typical real-world signals encountered by data acquisition and control systems. The signal types can be divided into three basic types: analog, digital, and pulse.

Analog signals are continuous in respect to time and amplitude. That is to say, for each value of time there exists one and only one amplitude value. It is the instantaneous amplitude measurement that is important. Unlike the infinite number of analog values, digital signals exist in only one of two possible states, i.e., on or off, true or false, or 1 or 0. The status of a digital point is what is measured. You have

SIGNALS SIX GENERAL CATEGORIES		
	Input (To Computer)	Output (From Computer)
ANALOG	Temperature Pressure Light Level Voltage Current	Chart Recorders Analog Instruments
DIGITAL	Sensing Switches Motors Valves Heaters Pumps	Activating Switches Motors Valves Heaters Pumps
PULSE	Flow Meters Liquid Gas Power	Stepping Motors Timed Valves Sound
	Event Counting	

Table 1. Six general categories of signals which are encountered in typical data acquisition and control systems.

no need to know how far on or off a motor or pump is but simply if it is on or off. Pulse signals are similar to digital signals except that you are not interested in the instantaneous status of a device but rather how often it changes its status. An example of such a device is a photocell on the production line of your favorite brewery which counts the filled beer bottles. You don't care whether a bottle is at the photocell, you do want to know how many have passed by the photocell.

In a data acquisition system, nonelectric signals (temperature, flow rate, motion, etc.) are converted to electrical voltages by means of transducers and sensors (thermocouples, RTDs, etc.). The front end to the host computer uses an analog-to-digital (A/D) converter which generates a binary number based upon the analog input voltage. The process is similar to measuring a pencil with a rule. The rule has a finite number of increments which allows you to measure within the limits. If you were to draw a horizontal line on a sheet of graph paper and count the number of full boxes from the bottom of the page to the line, you would have a measurement of the line's position in reference to the bottom graduation mark. Although there are an infinite number of places you could draw the line, there are only a limited number of positions which can be measured.

An analog-to-digital converter effectively performs the same process on voltages. It compares the voltage input to the full range of the converter and returns a binary number (or count) representing its relative

position (level) from the reference bottom.

The typical A/D converter is designed to convert *voltages* to a binary number. A problem arises when the signal under consideration is not a voltage, but a variable current or resistance. Some signal conditioning must take place before this signal can be hooked to an A/D converter. Many instruments generate a 4 to 20 mA current signal. These current signals are transmittable over long distances (approximately 4500 ft.) with little signal loss and sensitivity to noise (an advantage in factory environments). Figure 4 shows a common method used to convert current signals to a voltage which the A/D converter can monitor.

Solid-state temperature probes are another common source of current signals. These probes control the flow of current within a circuit in direct proportion to ambient temperature. The amount of current allowed to flow is usually 1 μ A per degree Kelvin.

Resistance signals are produced by sensors such as strain gauges and resistive temperature devices (RTDs). A resistance sensor is usually part of a *Wheatstone* bridge circuit. The front end data acquisi-

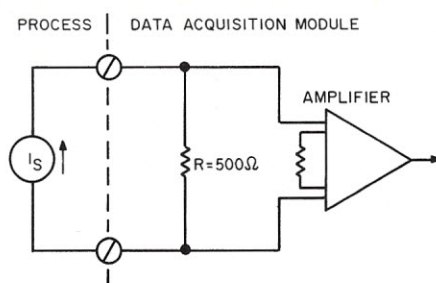


Figure 4. A method for converting current signals into voltage signals which can be read by an analog-to-digital converter. Resistor R must be a precision 500 Ohm resistor.

tion module should provide a facility for inserting the required bridge components.

The components required for a bridge circuit are a precision voltage reference and resistors (typically 0.05 percent precision). The resistive sensor is inserted as one element of the bridge. The output voltage is read across the bridge as shown in Figure 6.

Voltage V_{in} is the bridge excitation voltage. V_s is the bridge imbalance voltage. The value X is the fractional deviation of the sensing elements. All bridge elements are normally equal except the sensors which vary by a factor of $(1 + X)$.

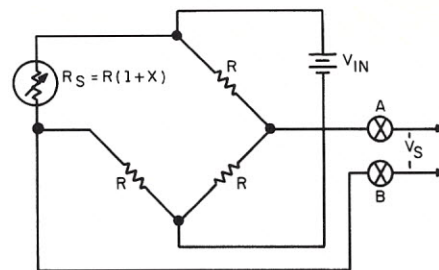
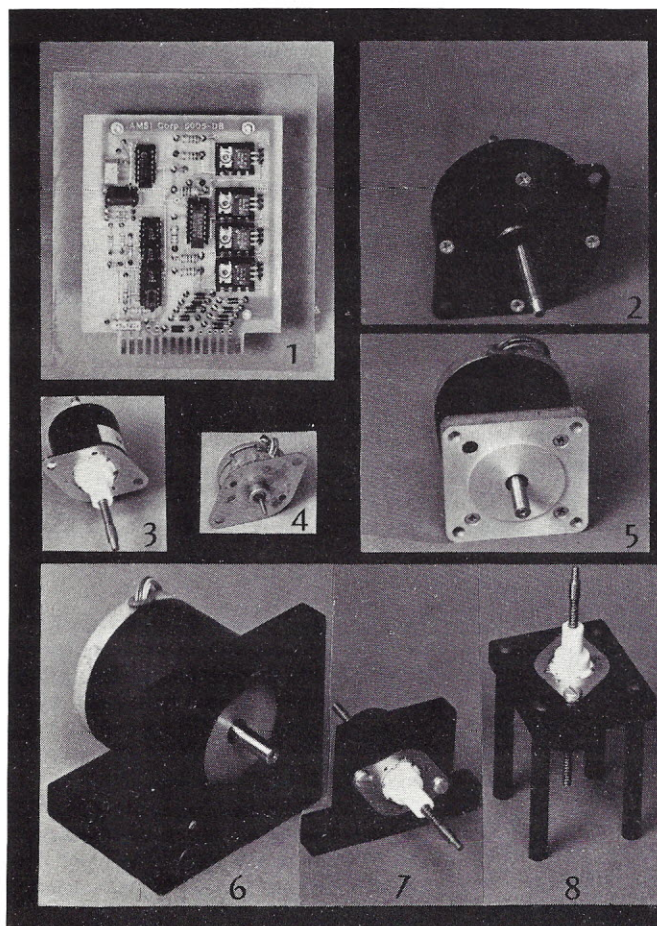


Figure 5. Resistive sensors such as resistance temperature devices (RTDs) and strain gauges present a varying resistance which can be detected by a Wheatstone bridge. The sensor is inserted as one part of the bridge. The voltage across the bridge can be monitored to detect changes in the sensor.

When all the elements in the bridge (the three resistors and the resistive sensor) have the same resistance value, the bridge is *balanced*. This means that the current flow in the left side of the bridge equals the current flow in the right and the voltage reading across the bridge is zero. As the sensor resistance changes (due to changes in temperature, pressure, etc.) the bridge becomes electrically unbalanced and produces a voltage (V_s). This voltage can then be measured by the front end data acquisition module.



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SIGNAL CONDITIONING

The voltage signals produced by many transducers often require *signal conditioning* before they can be read by an A/D converter. Although many voltage signals are in the range ± 1 to ± 10 V, some sensors such as thermocouples, photovoltaic cells, and piezoelectric sensors have a full-scale output range as small as ± 10 mV. This signal must be amplified before it can be accurately converted to a binary number.

The thermocouple is a common sensor that requires signal conditioning. The thermocouple is a junction of two dissimilar metals that produces a thermal signal voltage proportional to the junction temperature. Different types of thermocouple use a different pairs of metals and are distinguished by identifying letters. For example, thermocouple type J consists of iron and constantan, type K uses chromel and alumel, and type T uses copper and constantan.

Measuring the voltage from a thermocouple presents some unique problems. The very act of connecting the thermocouple to a voltmeter creates two new thermocouple junctions in series with the first. For example, assume you have a J-type thermocouple where one lead is iron and the other is constantan. Assume also that both leads are connected to copper probes as shown in Figure 6. These two new connections act as thermocouple junctions and create new voltages in series with the first. Since the connections are typically at a different temperature than the actual thermocouple probe, the connections generate a different voltage than the probe. The voltage is so small that it would typically not be a problem with typical connections. However, thermocouples themselves generate only very small voltages which are easily interfered with.

One way to counteract this problem is to immerse the new junctions in an ice bath. The new junctions are then held at a constant temperature and thus their effects upon the system are minimized. Unfortunately, ice baths have little practical use in the real world. Instead, a solid-state temperature probe is normally used to measure the secondary junction temperatures. These data can be used by the data acquisition system to compensate for the added thermocouple.

Why not use a solid-state sensor in the first place? Thermocouples measure an extremely wide range of temperatures and

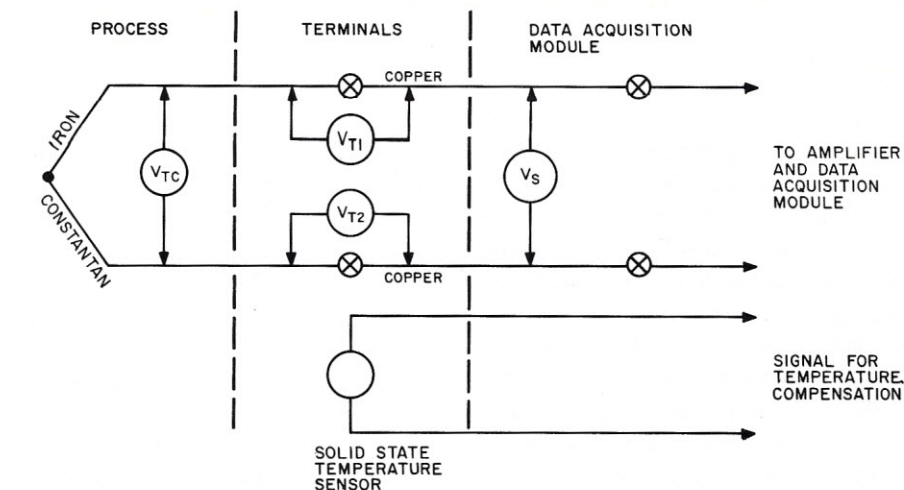


Figure 6. Measuring thermocouple voltages presents a unique problem since the act of connecting lead wires to the probe alters the output voltage. This problem can be offset by either maintaining the terminal connections at a known temperature (such as in an ice bath) or using a solid-state temperature probe to determine the terminal temperature. This reading can be used to compensate for the two additional thermocouple junctions.

can be made into a variety of forms. You can often weld them to the substance being studied. Solid-state probes have none of these advantages.

Another problem thermocouples present is that the low output voltage is not directly proportional to temperature. Each type of thermocouple has its own unique *voltage-vs-temperature* curve. Again, this problem should be solved by the smart data acquisition module. A good data acquisition module should perform the thermocouple linearization and cold junction compensation, and present the host with results in engineering units (i.e. degrees C).

Up to this point, we have assumed that you can simply connect a digital-to-analog converter directly to the voltage to be measured. Two basically different circuits are used to connect the D/A converter to the voltage source: single-ended input and differential input circuit.

A single-ended input circuit sends only the single voltage to the A/D converter. The reference ground is assumed to be the same for the front-end data acquisition module and the process (see Figure 7). Problems arise when the internal ground reference and signal ground reference are different. A ground potential difference shows up as a reading error, since the signal and ground are added (or subtracted depending on polarity). Most data acquisition systems provide an external connection so both the process and internal grounds can be tied together. This setup works well if the potential difference between the two grounds is small. A large

ground potential can cause reading errors.

If ground reference problems are expected, or if the signal levels are very low, then differential inputs provide better performance. Differential inputs amplify the difference between the input signal and its reference. If the signal must pass through an electrically noisy environment, then the noise should appear on both inputs to the front end. The difference between the noise on the signal wire and the noise on the reference is near zero. Thus, the noise is not amplified but the signal is. The noise

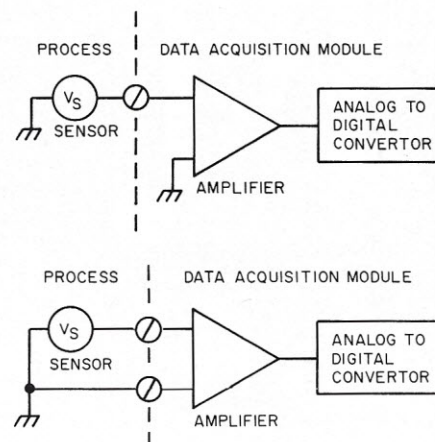


Figure 7. Single-ended versus differential analog input systems. The single-ended circuit transmits only the voltage to be measured to the data acquisition front end module. The process ground and the module ground are assumed to be identical. A differential input amplifies the difference between the voltage to be measured and its reference ground. This method can reduce errors due to noise since we can assume that noise will typically appear simultaneously on both the reference ground and signal lines. Since only the difference between the two signals is amplified, the noise effects are reduced.

is a common mode signal. The common mode rejection ratio (CMRR) of an analog input system is a measure of how it rejects voltages common to both inputs. The larger the CMRR number, the greater its ability to reject noise.

Signals entering the data acquisition front end module are often subject to induced high frequency noise. The noise may be induced by electromagnetic transmission or by stray capacitive coupling. If you intend to run signals over long distances, you should attempt to keep the signal wires separated, or shielded, from possible noise sources. Since this is not possible in many factory environments, additional filtering and surge suppression components must be used.

DIGITAL SIGNALS

The most common digital signals encountered in the real world are TTL (transistor-transistor logic) levels. These voltages indicate:

low at 0 to 0.8 V
high at 2.4 to 5.5 V

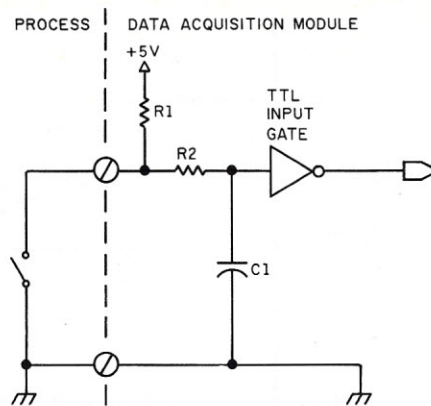


Figure 8. Many of the digital signals which need to be monitored are simply switches. Since a typical switch does not have its own built-in power supply, the data acquisition module must provide the power. Resistor R1 limits the amount of current sent through the circuit. Resistor R2 and capacitor C1 work to reduce the noise created when an electromechanical contact is made.

Normally, these signals do not need conditioning to connect with solid-state data acquisition systems.

A common type of digital signal found in industry is the *dry contact*. These signals are simply switches which are

opened and closed (see Figure 8). The front-end data acquisition module must provide the excitation voltage. In Figure 8, resistor R1 limits the current through the contacts (a 250 Ohm resistor allows 20 mA to pass through the circuit). Resistor R2 and capacitor C1 function as a debounce filter, eliminating erroneous input generated by the mechanical contacts bouncing when forced together. When the switch is closed, the input to the TTL data acquisition system is 0 V, when opened, the input is 5 V.

Not all digital signals operate at TTL levels. Relays are typically used to control voltages and currents beyond the range of TTL levels. Figure 9 shows a typical relay control situation. The TTL digital output controls the relay, and the relay controls the device. This works well until you need to use a relay that requires more than 24 mA at 5 V (maximum load for a TTL device).

Most good data acquisition systems provide digital isolation. Figure 10 shows an optical isolator block inserted between the TTL input and a switch controlling 24 V.

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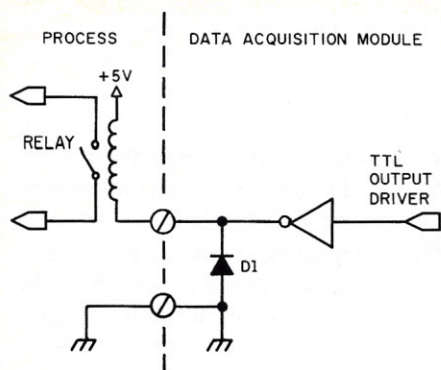


Figure 9. Not all digital devices operate at TTL levels. Relays are often used to drive voltages or currents beyond the range of TTL circuits. A simple TTL circuit can be used to drive the control relay.

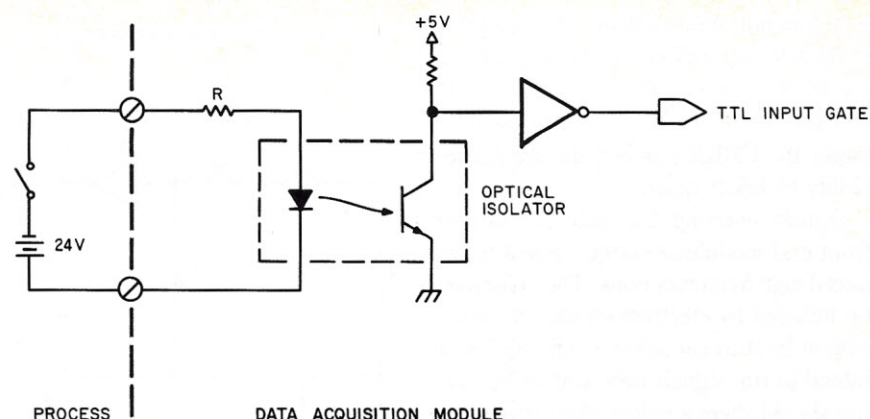


Figure 10. Optical isolators are used to protect the TTL level data acquisition circuitry from high-voltage real-world signals. The example circuit here shows an optical isolator that turns on when the input signal reaches 24 V. The signal which appears to the data acquisition module is at TTL levels.

The isolator converts the 24 V signal to an acceptable TTL level. Since the grounds of the 24 V signal and the TTL circuit are separated, several thousand volts of ground difference can exist between them.

One form of digital signal is the pulse signal. With pulse signals, you are not interested in the present state of the pulse,

but rather the number of pulses that have accumulated. An example is a bottle moving down a conveyor belt. The number of bottles that have passed a certain point on the conveyor can be counted by a simple photocell array that counts the number of times a beam of light has been blocked. Each time a bottle passes, it blocks the light. Each time the light is blocked, the

sensor transmits a pulse.

Data acquisition modules use *counters* to keep track of pulse signals. Counters are usually characterized by their length in bits and their maximum frequency input (how fast they can count). In addition to tracking how many pulses have been observed, counters can also be used to determine the frequency of a pulse train. You can determine the frequency by counting the number of pulses that arrive in a set period of time. For example, a motor that generated a pulse for each revolution would produce a pulse train with a frequency proportional to the speed of the motor (RPM).

A general-purpose data acquisition system as shown in Figure 11 provides a powerful and flexible monitoring system for industry and research labs. The system can be used to increase productivity and decrease overhead costs. Productivity is increased by eliminating the often manual job of entering data from experiments or monitoring instruments. The system can reduce overhead costs by monitoring machinery and machine environments to determine if they are operating at peak performance, in need of repair, or unable to keep up with current industry demands. With a little bit of forethought, general-purpose data acquisition systems can lead an automation revolution in small industries and laboratories.

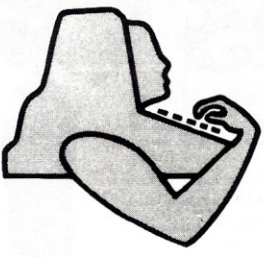
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A SIMPLE THERMAL TOUCH SENSOR

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Will future generations of robots have warm hands? Possibly, if they incorporate thermal touch sensors.

When you touch a piece of metal at room temperature, it feels cold. Room temperature wood, on the other hand, feels warmer. This observation can be explained as follows: Your blood supply heats your fingers to above room temperature. Contact with an object causes heat to be drawn from the fingers at a rate dependent on the object's material constitution. The resulting temperature drop in the skin is signaled to your brain and interpreted as sensations of cold and warmth. These sensations provide information about the differing thermal conductivity of the materials.

Over a limited range, the human hand and brain can also assess the thermal capacity of a touched object. An empty metal can is distinguishable from one containing a liquid. Although a room temperature metal can feels cold when first gripped, an empty can soon warms, whereas a full can remains cold to the touch. Information about thermal properties can also help you recognize new objects by giving an indication of the kinds of materials used in their construction.

In the Department of Electrical and Computer Engineering at Wollongong University, I have supervised two final year undergraduate projects aimed at developing a robot sensor capable of distinguishing between different materials, using the same principle as the human finger. This article contains details of the sensor construction and describes a method of analyzing its output.

a temperature-stabilized heat source, a layer of material of known thermal resistance to couple the heat source to the touched object, and a temperature transducer to measure the temperature near the point of contact between sensor and unknown object. As far as possible, within the constraints of available materials, the thermal sensor is modeled on the human thermal touch sense. This allows you to compare sensor readings with your own experiences. A diagram of the thermal sensor is shown in Figure 1.

In the case of a human finger, the blood supply provides heat to raise the finger temperature above ambient. This produces a surface temperature of about 30°C to 35°C. The touch sensor heat source consists of a 2N6123 transistor. The feedback stabilizing circuit shown in Figure 2 holds the transistor temperature constant by con-

trolling its power dissipation. A miniature negative temperature coefficient thermistor provides a measurement of the heat sink temperature. The 3140 operational amplifier compares the thermistor resistance with the setting of potentiometer *T1* and its output controls the bias current to the 2N6123 transistor. This in turn controls the transistor power dissipation and hence the heat sink temperature. Cyanoacrylate "super glue" is used to hold the thermistor in place (epoxy resin dissolves thermistor beads and should not be used). Leave a small gap between the thermistor and heat sink so that they do not make electrical contact.

The outer surface of the skin is simulated by a 3 mm thick layer of silicone rubber. I used Silastic 732 RTV silicone rubber, though any similar product for sealing sinks and showers would serve as well.

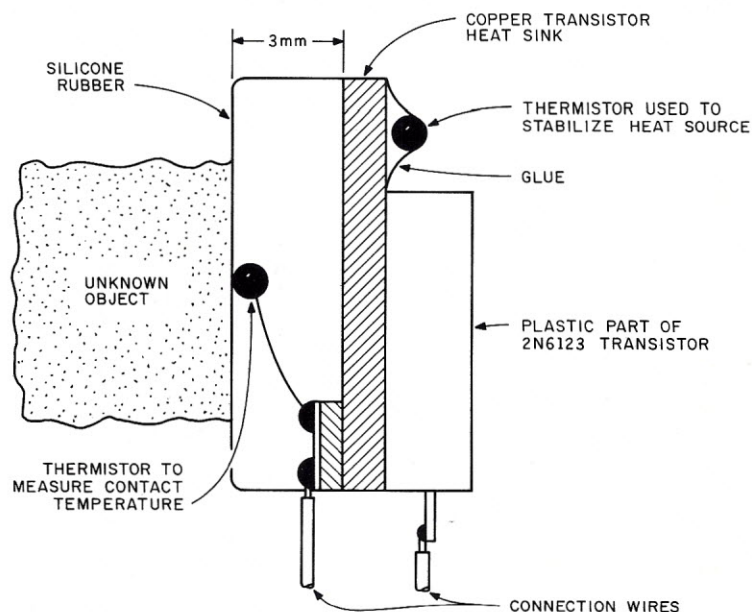


Figure 1. Thermal touch sensor diagram. The silicone rubber provides a pliant surface for making good thermal contact with the object to be sensed.

THE SENSOR

The essential parts of the sensor comprise

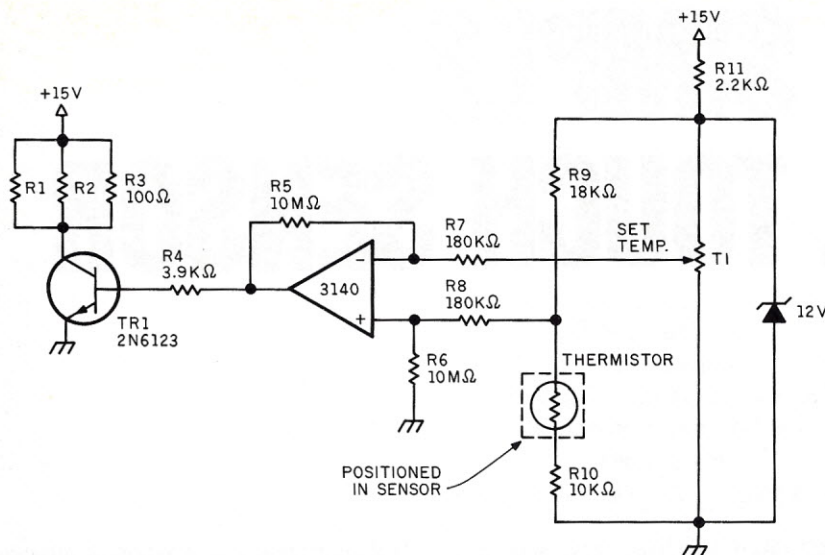


Figure 2. Heater stabilizing circuit diagram. The set temperature is determined by potentiometer *T1*. The feedback circuit maintains the base temperature for heating the sensor unit. All resistors are 1/4 W.

The silicone's elastomer properties ensure good thermal contact between the sensor and the touched object.

The thermistor used to measure contact temperature is embedded in the silicone rubber. Figure 3 shows the circuit used to amplify the DC level of this thermistor output. In Figure 3, transistor *TR1* and resistors *R5*, *R6*, and *R7* form a 0.6 mA current source to energize the thermistor. Amplifier *AMP1* is configured as a unity gain buffer to prevent loading the thermistor by *AMP2* which performs amplification and offset functions. After amplification, the signal is read by an analog-to-digital converter capable of reacting to voltages from -5 V to +5 V.

The following equations are used to calculate the thermistor temperature, *T*, based on its resistance, *R*:

$$R = V/I$$

$$T = B / [\ln(R/A)]$$

where:

A is a constant for the thermistor (0.34094 for our thermistor)

B is another thermistor constant (2500 for our thermistor)

I is the current through the thermistor (set at 0.6 mA by the current source)

R is the thermistor resistance

T is the thermistor temperature

V is the voltage drop across the thermistor

Two thermistor amplifier circuits are used. One amplifies the sensor contact temperature. The second is connected to a thermistor mounted on a metal plate for measuring ambient temperature. Unencapsulated thermistors were chosen for temperature sensors because of their small size and thermal mass combined with a large electrical output. The Phillips type 2322-

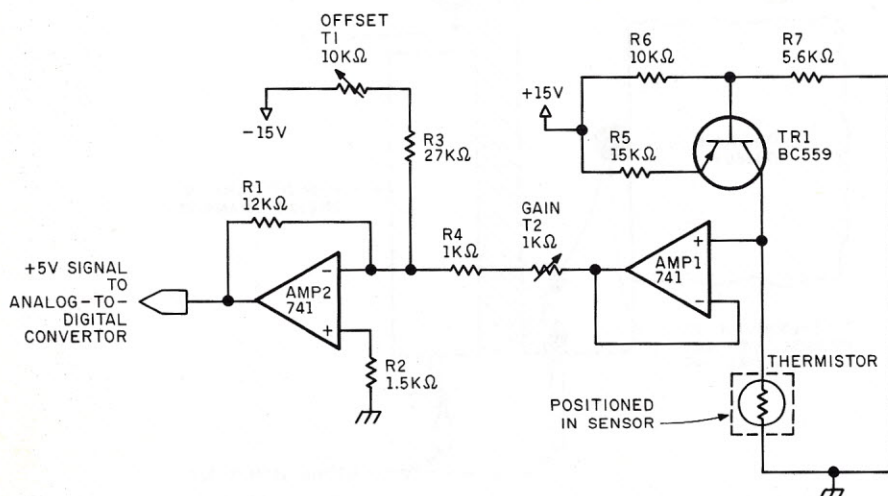


Figure 3. Thermistor amplifier diagram. Two amplifiers are used. *AMP1* provides a unity gain and sends its output to *AMP2* which performs the amplification and offset functions. All resistors are 1/4 W.

634-01152 thermistors used in this project are 1 mm in diameter and have a resistance of 1500 Ohms at 25°C. Any similar unencapsulated thermistor could be used providing the amplifier and heater circuits are modified to allow for any difference in thermistor resistance.

If suitable thermistors are not available, it should be possible to use thermocouple junctions. I have successfully employed an iron-constantan thermocouple to measure contact temperature. Extra amplification would be required since the thermocouple output voltage only changes about 1 mV for a 20°C temperature change.

The finished thermal touch sensor worked very well and was small enough to mount on the gripper of our Movemaster robot as shown in Photo 1.

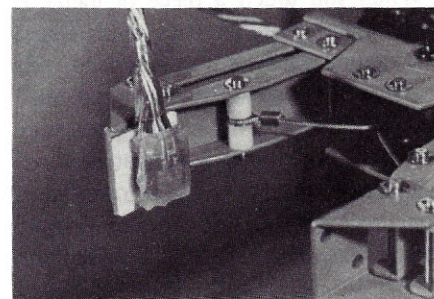


Photo 1. The thermal touch sensor mounted on the gripper of a Mitsubishi Movemaster robot arm.

RESULTS

Figure 4 shows graphs of the sensor output for three widely differing materials: polystyrene foam, paraffin wax, and aluminum alloy. Each graph is a plot of the results of applying a block of material to the sensor for 20 seconds and then removing it. These results agree with our own everyday experiences. Aluminum feels cold which corresponds to the large temperature drop on the graph. Paraffin wax feels less cold and gives a smaller temperature drop. After falling slightly, the graph of contact temperature for polystyrene foam rises above its initial value because the foam is a good insulator. This agrees with our own observation that polystyrene foam feels warm to the touch.

The temperature vs. time graph can be used to calculate the thermal conductivity and thermal diffusivity of a touched object. A simpler method of interpreting the sensor output is to calculate the percentage drop in sensor temperature towards ambient, *D* a fixed time after making contact:

$$D = [(T_i - T_c) / (T_i - T_a)] \times 100$$

where

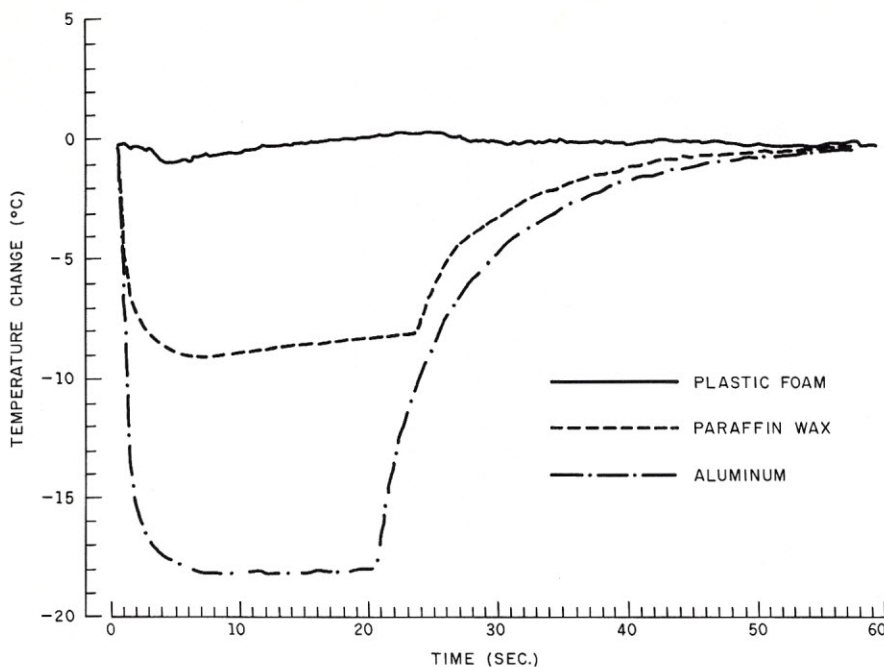


Figure 4. Graph of the thermal temperature response versus time. Three different blocks were placed in contact with the thermal sensor for 20 seconds and then removed. The resulting information can be used to help identify the type of object being held.

SENSOR PERCENTAGE
TEMPERATURE
DROP TOWARDS
AMBIENT (D)
AFTER 3 SECONDS
OF CONTACT WITH
UNKNOWN OBJECT

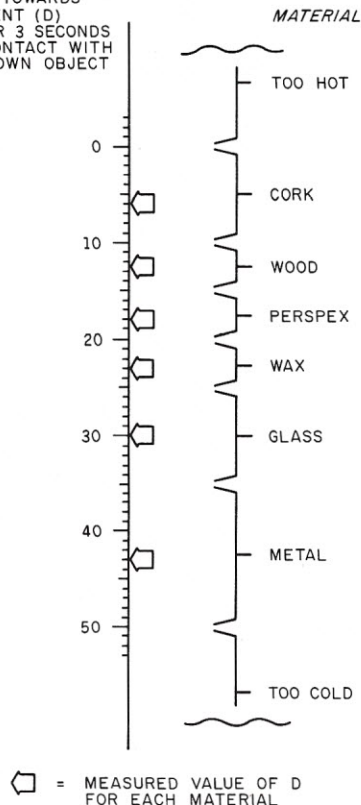


Figure 5. A simple way to thermally recognize a material is to make a graph of the sensor percentage of temperature drop towards ambient after 3 seconds of contact with an object, D . The arrows on this graph show the actual measured value of D during the learning session. The measured temperature during use can then be compared to this graph to determine the corresponding material.

D = percentage temperature drop towards ambient

T_i = initial sensor temperature

T_a = ambient room temperature

T_c = sensor temperature after contact

The calculated percentage temperature drop towards ambient three seconds after

contact can be used to distinguish between a range of different materials.

This method of analyzing the sensor output has been used to demonstrate the sensor's capabilities. For the demonstration, samples of cork, wood, perspex (lucite), paraffin wax, glass, and aluminum were prepared in 3 by 3 by 1.2 cm blocks. Values of percentage temperature drop D were measured for each material and these values were used to recognize the materials during the demonstration. The diagram in Figure 5 shows the values of D , found during the demonstration, that were assigned to particular materials.

Before the demonstration, each block was laid out in front of the robot in predetermined positions. The robot then went through a training session and learned the thermal properties for each block. Once the training session was over, the blocks were manually moved to a pick-up point and the robot was commanded to pick up the block, recognize it, and return the block to its allocated position. The sequence of robot movements during the recognition portion of the demonstration is illustrated in Figure 6. This procedure also takes into consideration objects with thermal characteristics beyond

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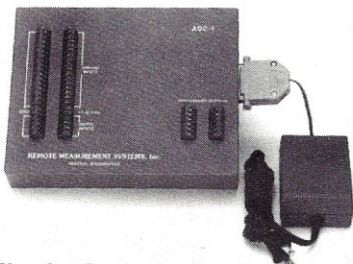
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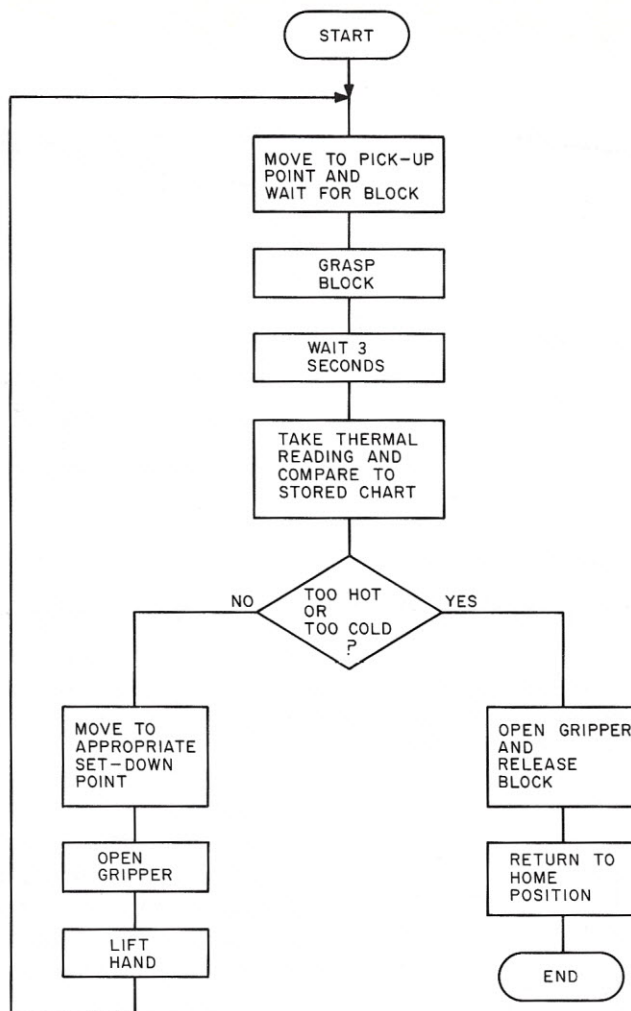


Figure 6. Flowchart detailing the robot's movements during the demonstration sessions.

the expected range. If the measured value of D is outside the expected range, perhaps because the block has been heated or cooled, the robot drops the block and returns to its home position. Photo 2 shows the Movemaster robot returning a recognized cork block to its allocated position. The demonstration performed very well and proved to be a fascinating illustration of robot sensory feedback.

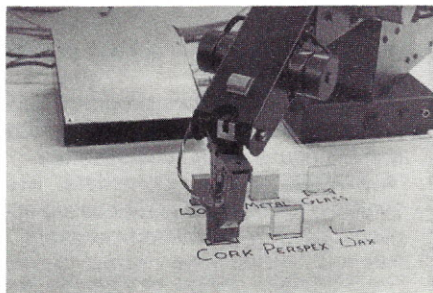


Photo 2. The Movemaster robot is seen here placing a block of cork onto its correct location. The cork block was found at a predetermined pickup point and recognized by its thermal characteristics.

CONCLUSION

In the future, when robots leave the highly structured environment of the factory production line and start moving around in the outside world, they will need a large range of sensory systems to avoid danger and to recognize and manipulate unfamiliar things. I am sure that thermal touch sensors will be one of the sensory systems required by these free-ranging robots.

Andrew Russell is a lecturer in the Department of Electrical and Computer Engineering at Wollongong University in Australia, where he lectures in digital electronics and computers. His main research interest is in robotics, particularly in the area of tactile sensors.

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EXPERIMENTING MADE EASY

Gerald Rues, Design Engineer
Electronic Systems and Instruments, Inc.
8301 Castle
Wichita, KS 67207

Experimenting with robotic and automation hardware usually requires you to be skillful in many disciplines. Until now, many people were limited in the kinds of experiments they could accomplish because of a lack of electronic know-how. A new computer interface device from Electronic Systems and Instruments, Inc. changes all that. The *computer interface device*, or *Cid*, provides a simple, fast, and convenient method of connecting hardware to personal computers.

Cid is designed to give experimentalists a simple and easy means of connecting sensors, actuators, and other accessories to personal computers, with a minimum amount of electronic know-how. The system can be controlled from BASIC, assembly language, or other high-level languages such as Pascal and FORTRAN.

The Cid concept performs the same type of computer interfacing function as does the computer monitor and keyboard. The main difference is that the Cid system links the mechanical world to a computer while the monitor and keyboard links humans with the computer. Figure 1 shows the similarities between the two systems.

CID HARDWARE

A basic Cid system consists of a power supply, a computer interface unit, and a computer interface cable. Cid is tailored to meet any experimental needs by adding up to eight snap-together Cid modules. Photo 1 shows a Cid stack with four modules installed.

The power supply is at the base of the stack. It delivers power to the eight modules and the computer interface unit. The computer interface unit snaps onto the power supply and is the main *translator* between the computer and the

modules. The computer interface unit converts electrical signals from a computer into a common set of signals used by all modules. Currently, interface cables exist for 11 different computer models. Some of them are: Apple II/II+ /IIfx, Commodore 64 and VIC-20, IBM PC and compatibles, and three Radio Shack models. Only the computer interface cable changes when connecting Cid to a different computer.

MODULES

A Cid module is an electronic circuit contained within a durable plastic case that performs a unique function or a specific task. Modules stack above the computer interface unit and do not require tools for installation. Some modules are for passing real-world data into a computer while other modules pass controlling information out to physical devices in the real world.

The two modules used in the following photocell experiment are the Analog Sensor Module and the Digital-to-Analog Module. The Analog Sensor Module is used with devices such as photocells and ther-

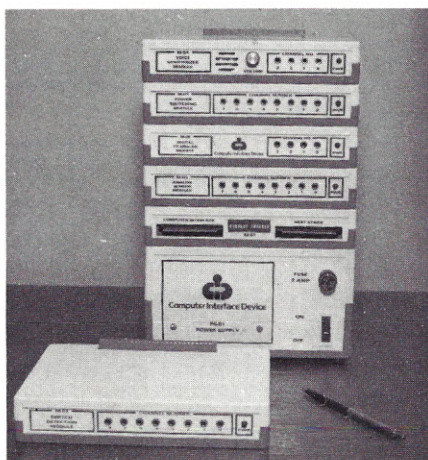


Photo 1. The computer interface device (Cid) with several interface modules and power supply.

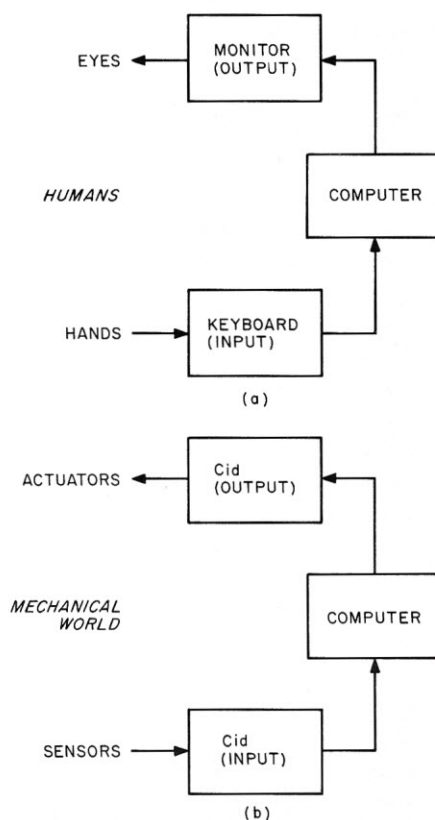


Figure 1. Comparison of the Cid interface and a normal computer keyboard and monitor. Figure 1a shows the human-to-computer interface. Figure 1b shows how Cid acts as the mechanical world-to-computer interface.

mistors that create resistive sensor information. The Analog Sensor Module converts this information into computer-compatible digital words. The Digital-to-Analog Module takes digital computer words and converts them into analog voltages.

Experimentalists can quickly program Cid using BASIC or another high-level language. Depending on the type of computer, Cid can be programmed using either PEEKs and POKEs or INP and OUT statements.

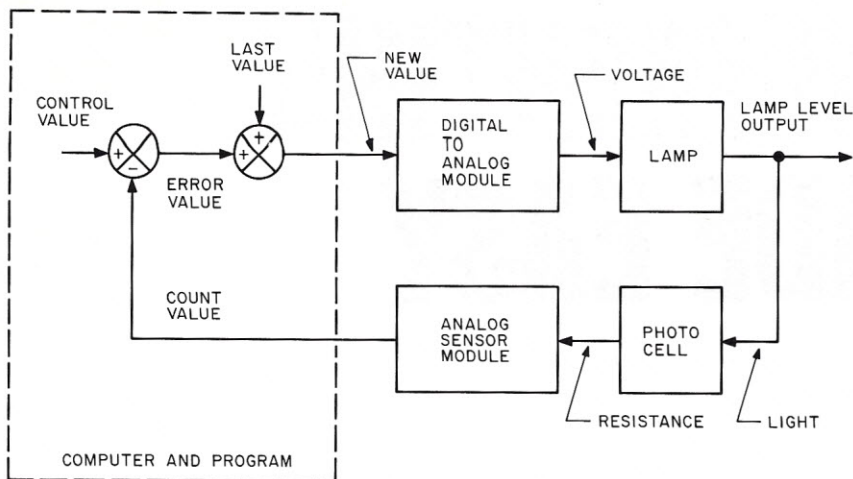


Figure 2. Block diagram showing the flow of information in the photocell feedback experiment.

PHOTOCELL FEEDBACK EXPERIMENT

A collection of physical hardware that gathers information, determines an error, and generates an action that tends to reduce the measured error is called a negative feedback system. The world of robots and automation is based on the negative feedback theory.

In the following experiment, a photocell and a light bulb are placed in an opaque tube. The objective of the experiment is to ensure the light bulb intensity follows the computer-generated control values. The hardware arrangement and the associated Cid modules and computer are shown in Photo 2. Figure 2 illustrates the signal flow in block diagram form.



Photo 2. Experimental setup for photocell feedback experiment.

The Cid Digital-to-Analog Module accepts an 8-bit digital word from the computer and generates a voltage proportional to the digital value. This voltage is used to power the light bulb. The light bulb's brightness varies in relation to the applied voltage. The light from the bulb travels down the tube and strikes the photocell at the other end. The photocell, sensing the amount of light it is receiving, changes

the resistance at its terminals to correspond with the amount of light at its light-sensitive surface. The Analog Sensor Module converts the resistance from the photocell into an 8-bit digital word that the computer reads. The computer and its program complete the loop by computing a new value and then return it to the Digital-to-Analog Module. The process is then repeated.

```

10 REM PHOTOCCELL / LIGHT BULB FEEDBACK PROGRAM
20 DIM Q(255)
30 CID = 499201 :REM C300 HEX ON FRONT OF CID
40 PHOTO=CID+27 :LIGHT=CID+47 :LEVEL=127
50 GOSUB 410:CLS:LOCATE 8,1
60 PRINT TAB(25) "--- FORCE CURVE FITTING DEMO ---":PRINT:PRINT:PRINT
70 PRINT TAB(25) "* PHOTOCCELL AT M-03 CHANNEL 3":PRINT
80 PRINT TAB(25) "* LIGHT SOURCE AT M-08 CHANNEL 3":PRINT
90 CONT.FREQ=1 :DFGAIN=.9:DFMOD.INDX=.5:DFNO.CYCLE=2.5:FB=127
100 REM START REPLOT SEQUENCE
110 GOSUB 440:CLS:LOCATE 10,1:OUT LIGHT,180
120 PRINT"ENTER GAIN CONSTANT (0-10);DEFAULT = ";DFGAIN:INPUT GAIN
130 PRINT"ENTER MODULATION INDEX (0-1);DEFAULT = ";DFMOD.INDX:INPUT MOD.INDX
140 PRINT"ENTER NUMBER OF CYCLES (1-10);DEFAULT = ";DFNO.CYCLE:INPUT NO.CYCLE
150 IF GAIN = 0 THEN GAIN = DFGAIN
160 IF MOD.INDX = 0 THEN MOD.INDX = DFMOD.INDX
170 IF NO.CYCLE = 0 THEN NO.CYCLE = DFNO.CYCLE
180 DFGAIN=GAIN:DFMOD.INDX=MOD.INDX:DFNO.CYCLE=NO.CYCLE
190 GOSUB 290:LOCATE 25,7:PRINT"FORCE CURVE FITTING . . . ";
200 FOR I=1 TO 255
210 OUT PHOTO,1:LL=255-INP(PHOTO)
220 FB=FB+(LL-Q(I))*GAIN
230 IF FB < 0 THEN FB=0
240 IF FB > 255 THEN FB=255
250 OUT LIGHT,FB:PSET(30+I,10+LL/255*150):NEXT I
260 LOCATE 25,7:PRINT"PRESS ANY KEY TO CONTINUE ";
270 IF INKEY$="" THEN 270
280 GOSUB 410:GOTO 100
290 REM ***** GRID PLOT *****
300 CLS:SCREEN 1:PSET(30,10):LINE-(30,160):LINE-(280,160):REM DELTA X=250
310 FOR I=1 TO 10:PSET(25,160-15*I):LINE-(30,160-15*I) :REM DELTA Y=150
320 PSET(30+25*I,165):LINE-(30+25*I,160):NEXT I
330 LOCATE 3,1:PRINT"P":LOCATE 5,1:PRINT"H":LOCATE 7,1:PRINT"O"
340 LOCATE 9,1:PRINT"T":LOCATE 11,1:PRINT"O":LOCATE 13,1:PRINT"C"
350 LOCATE 15,1:PRINT"E":LOCATE 17,1:PRINT"L":LOCATE 19,1:PRINT"L"
360 LOCATE 23,17:PRINT"T I M E";
370 LOCATE 25,7,1:PRINT"PLOTTING CONTROL CURVE . . . ";
380 PSET(30,85):FOR I=0 TO 255
390 Q(I)=127+MOD.INDX*127*SIN(NO.CYCLE*I*.02513)
400 LINE-(30+I,10+150*Q(I)/255):NEXT I:RETURN
410 REM ***** RETURN SCREEN TO NORMAL CONDITION *****
420 SCREEN 0,0,0:WIDTH 80:COLOR 7,0,0:RETURN
430 REM ***** PAUSE / CONTINUE *****
440 LOCATE 20,18:PRINT TAB(23)"PRESS ANY KEY TO CONTINUE OR X TO EXIT"
450 AS=INKEY$:IF AS="X" THEN LOAD"MENU",R
460 IF AS = "" THEN 450 ELSE RETURN

```

Listing 1. BASIC program for the photocell feedback experiment.

CONTROL VALUE

In every negative feedback system there must be a control value that the system is striving to maintain. This control value can be constant or it can be allowed to vary. In a home furnace system, the control value usually remains constant, say 68 degrees. The same is true in a sheet metal manufacturing process. Here, the separation of the final output rolling pins must be held constant to insure a consistent sheet metal output thickness. However, in an aircraft radar tracking system, the control value constantly changes as the aircraft being tracked moves across the sky.

Most of the program in Listing 1 is not involved in the data acquisition and control sequence. It initializes the hardware and system constants, plots the display grid, and generates the sinusoidal control values displayed in Photo 3. After the control values are tabulated in the BASIC array Q(255) and plotted on the screen, the program enters the feedback control loop. Lines 200 through 250 form the feedback control loop. Photo 4 shows the feedback tracking results. When this program was executed on a Compaq computer, one

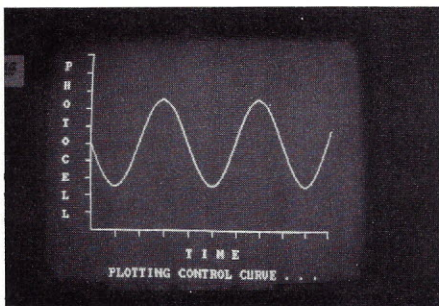


Photo 3. Sine wave generated for control values that the light bulb will be forced to follow.

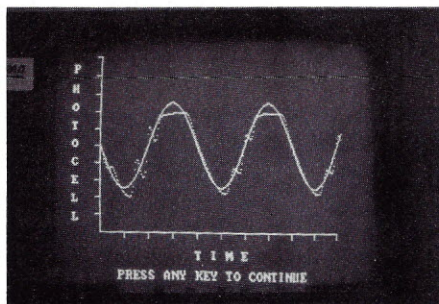


Photo 4. Initial feedback experiment results showing a problem on positive peaks.

complete sine wave was generated in approximately 2.8 seconds. This is an effective frequency of 0.36 Hz.

RESULTS

The results in Photo 4 show that the light intensity did not follow the control curve near the upper peaks of the sine curve. Why? Did the light bulb reach its maximum brightness for the voltage applied? Did the light intensity of the bulb get to the peaks while the photocell response did not? Or, did the system saturate? Having the experiment controlled by a computer and Cid (which was not economical several years ago) gives the experimentalist the flexibility to study the problem very easily. The answers to these questions can be found by writing other programs to look at the feedback system characteristics in more detail.

SECOND LOOK

The program in Listing 2 is used to examine the response of the photocell/light bulb apparatus in more detail. With menu selection 1, Consecutive Steps, the computer, through Cid, sends a series of step voltages to the light bulb starting at 0 V and increasing slowly to the full voltage of

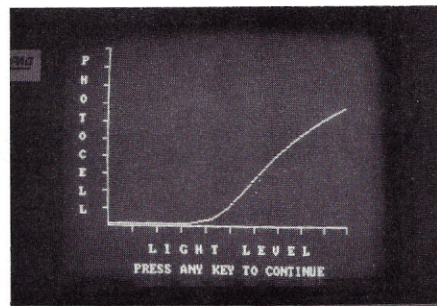
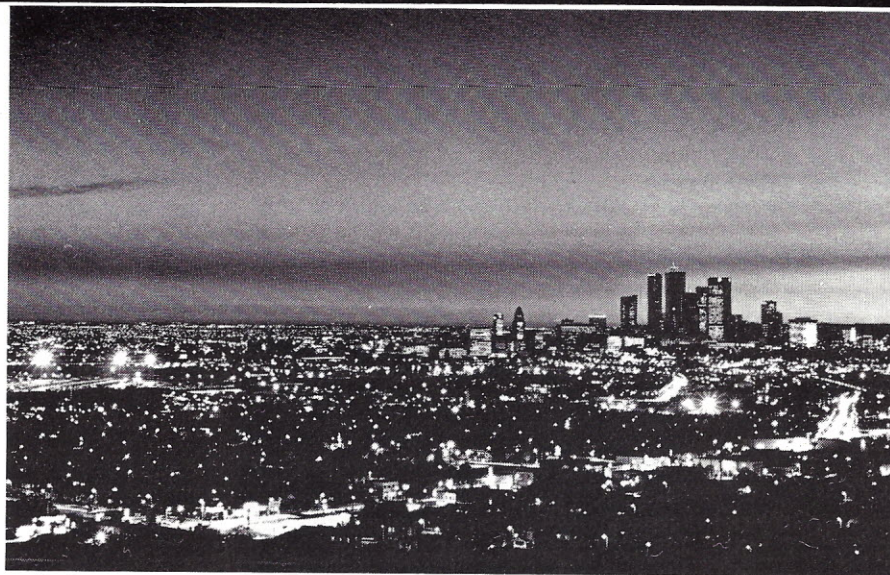


Photo 5. A graph of light bulb levels versus photocell readings. The light bulb brightness was increased in steady, even steps.

5 V. Each step is an increment of 0.0196 V. Photo 5 shows the results. The X-axis is light bulb voltage, 0 V to 5 V. The Y-axis is the photocell's readings of light bulb intensity. The Y-axis scale is from dark to full intensity. This plot reveals that the photocell readings never went past 70 percent of full scale, and shows why the positive sine wave peaks are flat in Photo 4. If the sine wave control curve is decreased slightly, the feedback experiment should work correctly.

Photo 5 also indicates that the photocell and light bulb did not respond at low light



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```

10 REM PHOTO CELL STUDY
20 DIM Q(250):DELAY=10
30 CID = 499201:REM C300 HEX
40 PHOTO =CID+27:LIGHT =CID+47:LEVEL=127
50 GOSUB 490:OUT LIGHT,0
60 CLS:PRINT:PRINT:PRINT
70 PRINT TAB(27)"PHOTO CELL STUDY DEMO":PRINT
80 PRINT TAB(25)"PHOTOCELL AT M-03 CHANNEL 3":PRINT
90 PRINT TAB(24)"LIGHT SOURCE AT M-08 CHANNEL 3"
100 GOSUB 530
110 IF A$="" THEN 100
120 CLS:LOCATE 15,30:PRINT"1 - CONSECUTIVE STEPS":PRINT
130 PRINT TAB(30)"2 - RANDOM STEPS":PRINT
140 PRINT TAB(30)"3 - SET DELAY":PRINT
150 PRINT TAB(30)"X - EXIT"
160 A$=INPUT$(1):IF A$="1" THEN 200
170 IF A$="X" THEN LOAD"MENU",R
180 IF A$="2" THEN 280
190 IF A$="3" THEN 560 ELSE 120
200 REM PLOT FROM 0 TO 255
210 GOSUB 400:FOR I=1 TO 250:OUT LIGHT,I
220 FOR D=1 TO DELAY:NEXT D
230 OUT PHOTO,1:Q(I)=255-INP(PHOTO)
240 PSET(30+I,10+Q(I)/255*150)
250 IF INKEY$="X" THEN GOSUB 490:GOTO 120
260 NEXT I:OUT LIGHT,0
270 GOSUB 370:GOSUB 490:GOTO 120
280 REM PLOT AT RANDOM
290 GOSUB 400:FOR I=1 TO 250
300 IF INKEY$="X" THEN GOSUB 490:GOTO 120
310 LL=INT(RND*255):OUT LIGHT,LL
320 FOR D=1 TO DELAY:NEXT D
330 OUT PHOTO,1:Q(I)=255-INP(PHOTO)
340 PSET(30+LL,10+Q(I)/255*150)
350 NEXT I:OUT LIGHT,0
360 GOSUB 370:GOSUB 490:GOTO 120
370 REM ***** CONTINUE PAUSE *****
380 LOCATE 25,8,1:PRINT"PRESS ANY KEY TO CONTINUE";
390 IF INKEY$="" THEN 390 ELSE RETURN
400 REM ***** GRID PLOT *****
410 CLS:SCREEN 1:PSET(30,10):LINE-(30,160):LINE-(280,160):REM DELTA X=250
420 FOR I=1 TO 10:PSET(25,160-15*I):LINE-(30,160-15*I):REM DELTA Y=150
430 PSET(30+25*I,165):LINE-(30+25*I,160):NEXT I
440 LOCATE 3,1:PRINT"P":LOCATE 5,1:PRINT"H":LOCATE 7,1:PRINT"O"
450 LOCATE 9,1:PRINT"T":LOCATE 11,1:PRINT"O":LOCATE 13,1:PRINT"C"
460 LOCATE 15,1:PRINT"E":LOCATE 17,1:PRINT"L":LOCATE 19,1:PRINT"L"
470 LOCATE 23,10:PRINT"L I G H T   L E V E L";
480 RETURN
490 REM ***** RETURN SCREEN TO NORMAL CONDITION *****
500 SCREEN 0,0,0:WIDTH 80:COLOR 7,0,0:RETURN
510 CLS:LOCATE 20,15:RETURN
520 REM ***** CONTINUE *****
530 LOCATE 20,20:PRINT"PRESS ANY KEY TO CONTINUE OR X TO EXIT"
540 A$=INKEY$:IF A$="X" THEN LOAD"MENU",R
550 IF A$="" THEN 540 ELSE RETURN
560 REM ***** SET DELAY *****
570 CLS:LOCATE 15,20:INPUT"ENTER NEW DELAY VALUE (0-2000)",DELAY:GOTO 120

```

Listing 2. BASIC program for photocell study program.

levels. Examining the light bulb while the program is running reveals that the bulb does not actually glow at low voltage levels. Therefore, it is reasonable to conclude that the flat portion of the curve is caused by the light bulb's inability to glow at low voltage levels.

Let's look at some other important characteristics of the system. The same test will again be executed, but this time random voltages will be sent to the light bulb instead of consecutive voltages. To do this, select menu selection number 2, Random Steps. The results in Photo 6 appear very disordered. To see if response time could be the culprit creating this disorderly plot, generate another random point plot. This time, increase the time delay loop in line 320 from 10 counts to 1000 counts. The results are shown in Photo 7. The results

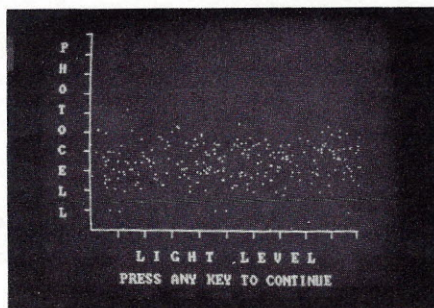


Photo 6. This graph was created by using a random-voltage generator and a short delay loop before reading the photocell value.

of these two plots demonstrate the time dependency of the photocell/light bulb apparatus.

CONCLUSION

The desired control plot is shown in Photo 8. Achieving this result required that the

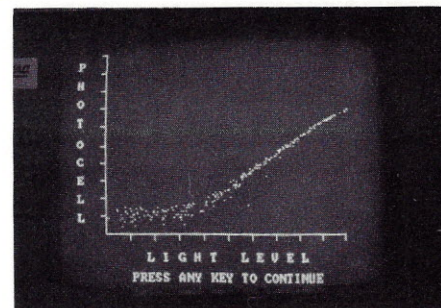


Photo 7. This graph was created by using the same program as in Photo 6 except, in this example, the delay loop between generating the voltage to the light bulb and reading the photocell value was increased from 10 to 1000.

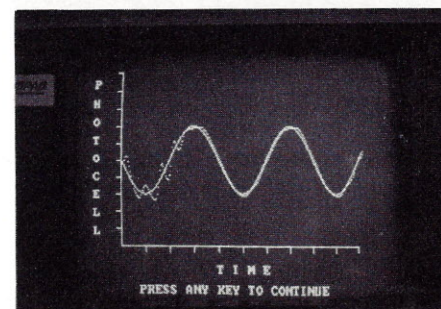


Photo 8. The final results of the photocell feedback experiment including all the knowledge learned from previous experiments.

control values be decreased slightly. Another option could have been to lower the total sine wave curve.

Without the computer and Cid, a detailed investigation of this simple feedback system would have taken a significant amount of effort. Experiments such as this one are easy to set up and run with a personal computer and Cid.

Whether you have very little or quite a lot of electronics experience, the Cid system is a fast, simple, and convenient building block interfacing system that frees you from worrying about detailed electronic tasks. The immediate benefit is more time to spend at experimenting and understanding the particular project. The Cid/computer combination also gives you the capability and flexibility to examine a project from angles that were previously not possible.

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72	82	92
Excellent	Good	Fair

Product Notes

Problem: how to use your computer to gather data such as light, pressure, fluid flow, wind direction, and temperature, without purchasing thousands of dollars worth of additional equipment.

Solution: the ADC-1 data acquisition system from Remote Measurement Systems, Inc.

The Remote Measurement System's ADC-1 is a low-cost, easy-to-operate data acquisition and control system. The ADC-1, shown in Photo 1, allows a computer to gather information from the surrounding environment. It measures a sensor's analog voltage output and converts this to a digital number. The ADC-1 can also be used to control external devices over AC power lines. An onboard computer, sensor, and control interface, limits the need for sophisticated electronic or programming skills to acquire real-world information.

The ADC-1 provides 16 analog input channels coupled with a 12-bit analog-to-

The ADC-1 Data Acquisition System

RAYMOND GA COTE

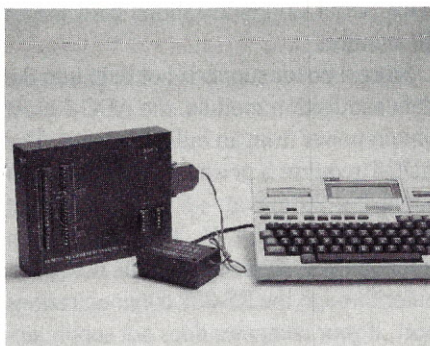


Photo 1. The ADC-1 from Remote Measurement Systems, Inc. can be connected with any computer system with an RS-232 port. The small blue box with the electrical cord shown here is the BSR controller. It has been built into a separate box to reduce electrical noise problems.

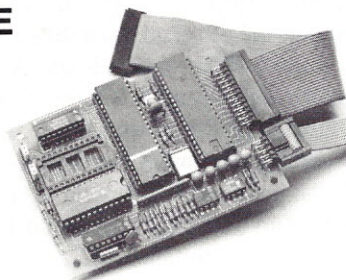
digital (A/D) converter. Four digital inputs are available for monitoring or counting digital signals. A BSR controller module (a standard part of the system) permits you to remotely control appliances and lamps via signals transmitted over AC wiring to BSR modules. The entire operation is controlled via standard RS-232 connections.

CONNECTING THE SYSTEM

The amount of time it takes to connect the ADC-1 data acquisition module to your computer is inversely proportional to the number of times you have connected RS-232 serial cables. The only procedure required for using the ADC-1 is to wire a four-wire RS-232 connector between your computer and the module and provide a source of power.

The four-wire connection between the ADC-1 and the computer consists of a wire for ground, a wire for power, and data transmission and reception wires. To help you in the sometimes bewildering world of

THE NEW ONE



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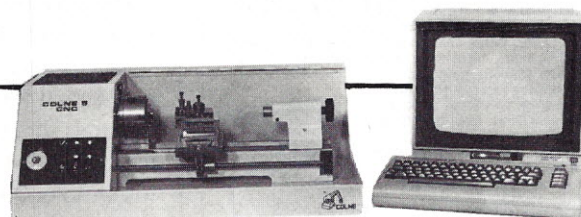
The new MC-1Z joins the MC-1N and MC-2N in Basicon's family of low-cost microcontrollers. Fully self-contained, all three are quickly and easily programmed using BASIC language. Add an RS-232-compatible terminal and you have a complete and versatile applications programmer. Basicon also offers peripherals and accessories to help you make up complete operating systems.

FEATURES:	MC-1Z	MC-1N	MC-2N
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RAM, kbytes	2-16	2	4
EPROM, kbytes	4/8	2/4	2-8
I/O lines	40	29	53
Interrupts	6	2	2
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Unit Price	\$159	\$139	\$219

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SWITCH YOUR MICRO TO CONTROL TECHNOLOGY CNC 5 Lathe

The Lathe has a centre height of 70 mm and is compact and portable. Overall dimensions are 680 mm length, 445 mm depth, 240 mm height. Total weight is 40 Kg. Drive electronics are tray-mounted at the rear of the machine. The Lathe is designed to interface to any parallel-port 8 bit micro computer. The basic software provides a comprehensive range of G-codes and the facility to accept and retain complex cutting sequences. A variable-scale emulator provides graphics for tool path verification. Other software features

include editing, update of current software block and safety measures. Currently available for BBC and Commodore 64 computers.

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Chuck size	80 mm
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AUTOMATION NEWS

The Newspaper for Flexible Manufacturing June 8, 1984 \$3.00 (U.S.)



Republicans Release Program To Spur High Tech Innovation

WASHINGTON, June 7—The House of Representatives today released a bill that would provide \$1.5 billion in tax incentives to encourage high-tech research and development. The bill, known as the Small Business Technology Transfer Act, would allow small businesses to deduct up to 75% of the cost of research and development from their federal income taxes. The bill also provides for a 15% credit for research and development expenses. The bill is expected to pass the House in the near future.

Panasonic Enters Pana Robo In U.S.

NEW YORK, June 7—Panasonic Corp. has announced that it has entered the U.S. market with its new Pana Robo, a line of industrial robots. The robots are designed for use in a variety of manufacturing applications, including assembly, welding, and material handling. The robots are available in a range of sizes and configurations to meet the needs of different manufacturing environments.

Toyoda Regains Machining Ctr's

TOYOTA, Japan—Toyoda Machine Works has announced that it has regained control of its machining centers in the U.S. market. The company had previously lost control of these centers to a group of investors, but has now successfully negotiated a deal to reacquire them. The company is pleased with the outcome and expects to continue its operations in the U.S. market.



IR/1 P256 Building Block For GMF Vision System

NEW YORK, June 7—The IR/1 P256 Building Block is a new addition to the GMF Vision System. It is designed to provide a high level of accuracy and reliability in vision applications. The building block is easy to install and use, and is compatible with a wide range of vision systems. It is expected to be a popular choice for manufacturers looking to improve their vision capabilities.



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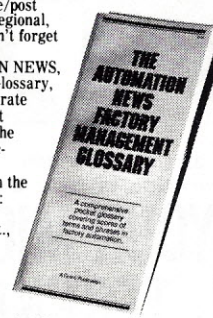
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RS-232 connections, the ADC-1 documentation provides wiring connection tables for many popular computers. This section of the manual is continuously being updated as the ADC-1 module is used with more computer systems. At present, detailed connection instructions are provided for Apple, Macintosh, Atari, Commodore, Epson, IBM, Kaypro, NEC, Northstar, Osborne, and Radio Shack computers. The information is sufficient that I was able to construct a proper cable for an Apple II+ computer using a California Computer Systems Serial Communications card within 10 minutes.

Since a power supply is not built into the data acquisition module, the ADC-1 must obtain power from an outside source. The ADC-1 requires a power source capable of supplying 20 mA at +5 V or 35 mA at from +6 to +24 V. This power can sometimes be obtained from the host computer through the RS-232 communications port. If your computer does not supply sufficient voltage, a standard 9 V transistor battery can supply power for several weeks of normal usage. To someone like myself who wants to just plug things together quickly and run, having to wire in a battery was a bit of an annoyance. However, I have been using that same battery off and on for two months without any trouble.

Anyone who has had some experience connecting RS-232 cables to various peripherals should have no trouble connecting the ADC-1 and having it operational within 15 or 20 minutes of first unpacking the system.

GATHERING INFORMATION

The Remote Measurement Systems ADC-1 is a command-driven data acquisition system. Your computer program must provide explicit instructions to connect a particular analog channel to the A/D converter, start the conversion, and transmit the data back to the computer system. Because of this very active interaction between the computer and the data acquisition module, the ADC-1 is not ideal for applications requiring rapid, precise time-slice measurements. However, this was a specific tradeoff done in the interest of economy.

Keith Ronholm, President of Remote Measurement Systems, Inc., feels that many data acquisition applications are not so time-critical. Typically, you do not need a very expensive system to monitor soil acidity, rainfall, pressure in an experiment, refrigerator temperature, overall amplitude

of light in a room, electrical power consumption, etc. The ADC-1 is designed to work with relatively slowly changing data. Of course, "slowly changing" in this case is still measured in milliseconds.

Data acquisition commands and results are communicated over the RS-232 link via a series of 8-bit bytes. In the command byte structure, the four main module activities (start analog-to-digital conversion, set the controlled outputs, reset latched digital inputs, and transmit commands using the BSR controller) are controlled by the two high-order bits, 7 and 8. The other six bits modify the specified action.

The most common command is the order to start an analog-to-digital conversion. Sending a command byte with bits 8 and 7 set to binary 00 indicates that a conversion should be started. Command byte bits 1 through 4 are used to select one of the 16 analog input channels. Bit 5 is used to select either an optional onboard instrumentation amplifier or a built-in temperature sensor. The internal software is arranged so that the onboard instrumentation amplifier can only be used for analog inputs 1 through 8. This means that bit 4 is always off. When both bits 4 and 5 are on during an analog-to-digital conversion start command, the built-in onboard temperature sensor is selected.

A command byte with bits 8 and 7 set to binary 01 indicates that the controlled outputs will be set on or off. Bits 1 through 6 control which output is set. A 1 turns on the output and a 0 turns it off.

A command byte with bits 8 and 7 set to binary 10 simply resets the latched digital inputs. It is also used to return information about various digital I/O lines and data acquisition values.

A command byte with bits 8 and 7 set to binary 11 is used to transmit data on the AC powerline to BSR controller modules. Every time a command byte is sent to the ADC-1, a response byte is returned to the controlling computer. The simplest way to operate the ADC-1 is to send command bytes with bits 7 and 8 set to binary 00, 01, or 11 when you wish the ADC-1 to perform a task, and set to binary 10 when data is desired. The data returned when the command byte's high bits are binary 10 is determined by the other six bits.

Since a response byte is returned every time you send a command byte, you should make sure you read the response byte every

time, even if you do not need the returned information. This ensures that you are receiving the proper response to your most recent command. Another reason to always read the command byte is to ensure that commands do not overlap. For example, when you initiate a data conversion command, you must not issue another data conversion command until the first one is complete. The only way of knowing the first conversion is complete is by waiting for the data byte to be returned. If you issue a second data conversion before the first is finished, the returned data will be useless. The same problem appears when sending information with the BSR controller. You cannot instruct the BSR controller to transmit a second message until the first message has been completed. Once again, your only indication that the message has been transmitted is the returned data byte. By always waiting for the return data byte, you can guarantee that the previous command was completed.

Once you become familiar with the system, you can instruct different parts of the ADC-1 to perform functions without waiting for the return data byte. For example, you can instruct the A/D converter to start

a conversion and then send a message on the BSR controller. Since neither of these operations interferes with the other, they can be performed simultaneously. However, remember to keep track of which return data byte is due first and also remember to read both bytes of information.

Communications with the ADC-1 depend on your particular computer system and how your RS-232 communications port is configured. The ADC-1 documentation provides example programs written in Microsoft BASIC and specific examples for various computer systems. Communications may be via port I/O commands, memory mapped communications ports, or through simple read and write statements.

SENSORS

The ADC-1 is designed to monitor voltage variations. Any sensor which generates a voltage signal can be connected to the ADC-1. An optional instrumentation amplifier is provided for use with sensors, such as thermocouples, that generate a very small voltage. The typical input to the 16 analog channels must be limited to ± 5 V.

Since Remote Measurement Systems, Inc. is concerned about providing inexpensive, reliable data acquisition systems, they

have also searched for reliable, inexpensive sensors which work well with the ADC-1. The documentation contains a chapter describing thermistors, electrical energy consumption sensors, optical encoders and other sensors. The documentation provides part numbers and company names, and also shows how to connect the sensors to the ADC-1.

CONCLUSION

Remote Measurement Systems' ADC-1 is an economical way to add simple data acquisition facilities to any computer with an RS-232 port. The \$395 price includes the basic module, the BSR controller, and one built-in temperature sensor. The ADC-1 can handle many different data acquisition tasks and provides an excellent test bed for developing equipment to respond to real-world events. Coupling the ADC-1 with the newer portable and lap-top computer systems results in a flexible, portable data acquisition system.

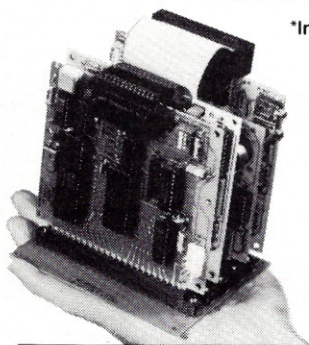
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Of Mice and Machines

E. Francis Avila
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The first annual Central California Area, Region Six, IEEE MicroMouse contest, scheduled for April 28, 1984 on the University of California/Berkeley campus, got off to a less than flying start.

Five teams had officially entered the IEEE-sponsored student MicroMouse contest, but due to various problems, none of the five made it to post time. The MicroMouse contest was to be the highlight of a day-long conference sponsored by the Central Area student chapter. The five official teams that entered came from the Berkeley Campus, Cal State University/Sacramento, and Cal State University/Chico.

According to conference spokesman Dan Pugh, three teams were from the Berkeley campus. John Fong headed a team whose members were Richard Adachi, Glenn Lee, and Nanoo Staal. All are electrical engineering/computer science (EECS) majors. A second team of Berkeley students was headed by Peter Hack, (CS). Members included John Whelan (EECS), Brad Krebs (EECS) and Bennett Feld (CS). A third MicroMouse team was led by Steven Schoettler (EECS). No further information was available on this team. The Sacramento State campus was represented by Roger Petersen, Ken Gillam, and Carro! Hoagland, all EE majors. No information was available on the Chico State team since they did not attend the conference.

Only the Sacramento team actually arrived at the conference with their robotic mouse. Unfortunately, their mouse was not ready for the race. As is often the case in projects of this complexity, the mechanical portion of the mouse was ready, but the software was not.

"The students generally don't realize the work involved in a project of this magnitude," commented Prof. Mahlon D. Heller, IEEE student activities coordinator and engineering instructor at the University of Nevada/Reno. "The point of the contest and the conference is to give the stu-

dent experience in presenting papers and working on projects as a team."

"I'm not disappointed that none of the robots were ready to run," continued Prof. Heller, "I kind of expected this. It's been a good learning experience."

Just hours before the contest was to be held, one Berkeley team was frantically calling Bay Area Radio Shack stores trying to locate driver transistors that had been inadvertently destroyed during testing.

All contenders felt that they would like to return next year and attack the problem again.

RULES

The MicroMouse ground rules are relatively simple. Each robot must be built by a team of students using commonly available parts. A maximum of \$500 can be spent on parts. The price of each com-

ponent is based on current off-the-shelf prices. A detailed price breakdown must be supplied to the judges at contest time.

The mouse must be completely self-contained. It can not hop, run, fly, or climb over the maze walls. Nor may it cut, burn, or in any way attempt to penetrate the walls in a manner that damages the maze.

Each mouse is expected to make three official runs, with a maximum of five minutes allowed per run. The best time out of the three runs determines the standings. The mouse may not be touched once it begins and no extensive robot system modifications are allowed during the contest.

According to the rules, "Switches may be set to alter algorithms, but no attempts may be made to program mouse control on the basis of maze configuration." This means that the robot, on its own, must learn from its mistakes and *calculate* its way out of the maze.

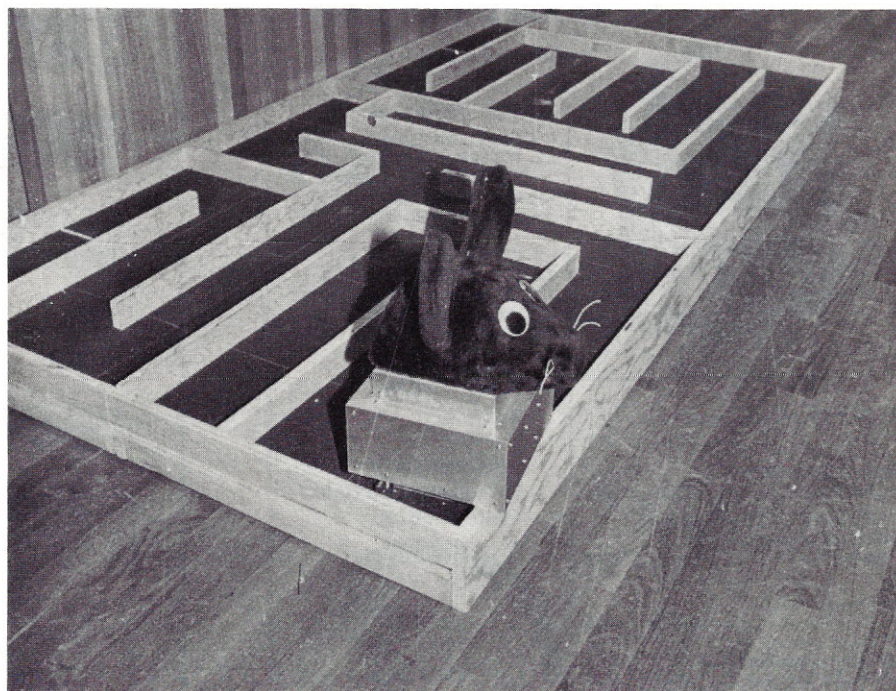


Photo 1. Shown here is the California State University/Sacramento entry into the MicroMouse contest. Its creators, Carroll Hoagland, Roger Petersen, and Ken Gillam, worked for three months preparing for the contest. The robot, a 6809-based system using sonar and LED sensors for guidance, was mechanically ready but had incomplete control algorithms. The builders vowed to return next year.

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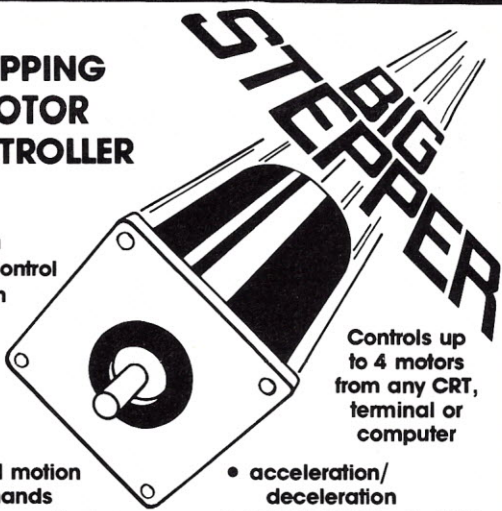
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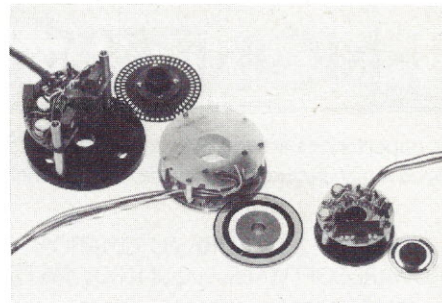


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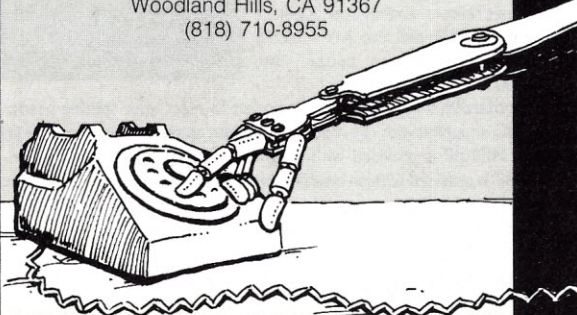
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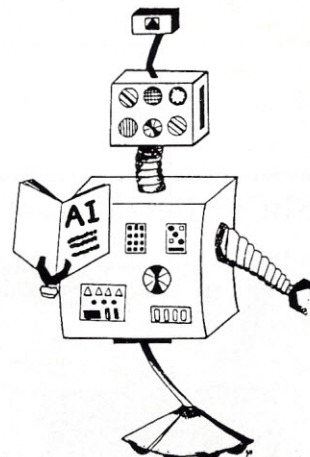
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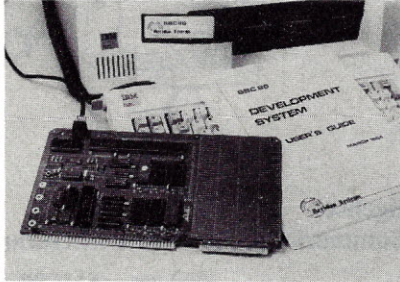


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New Products

SBC88 Development System



The SBC88 is a high-performance, low-cost development system specifically designed for IBM PC and PC-compatible users as a hardware/software nucleus, on which they can build dedicated microprocessor-based packages at a fraction of the cost required by conventional development methods. This design takes advantage of the fact that users of the IBM PC already have a significant part of the traditional software development system.

The SBC88 hardware kernel is an operating 8088 processor with pseudo-static programmable memory, latched and buffered interface signals, monitor PROM, and an 8251A-based RS-232 link to a serial port on the IBM PC. An 8255A parallel interface adapter provides 24 general-purpose I/O lines. It also includes three channels of the 8253-5 counter/timer and eight interrupt lines on the 8259A interrupt controller.

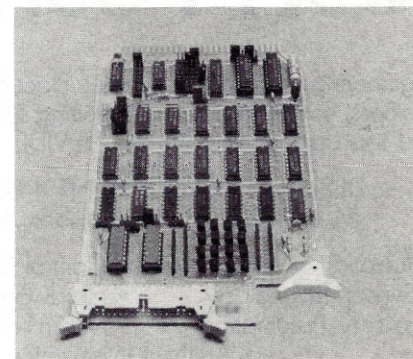
A 4 by 6 in. onboard wirewrap area pro-

vides room for hardware development projects. The Multibus board configuration provides a flexible package with plenty of I/O possibilities through the edge connectors and ribbon cable headers. Only the power and ground contacts of the Multibus connectors are dedicated.

The SBC88 Monitor Software provides the link between the target hardware and the IBM PC. The onboard PROM performs hardware initialization, handles the communication between the SBC88 hardware and IBM PC, provides utility routines and supervises the debugging feature. Programs can be developed on the IBM PC and downloaded to the SBC88. The Monitor functions as a transparent link between the IBM PC peripherals and the target board. The system has the functional appearance of having the keyboard, display screen, and diskette drives directly connected to the SBC88 hardware. A printer can be connected to the PC to provide hard copy of the debugging information. All data transmission between the PC and the SBC88 board use error checking and auto retransmit.

The SBC88 development system is priced at \$500.00. For additional information, contact: Spencer Chen, Meridian Systems, 321 Aviator St., Suite 111, PO Box 3034, Camarillo, CA 93011, telephone (805) 484-8696.

Circle 40



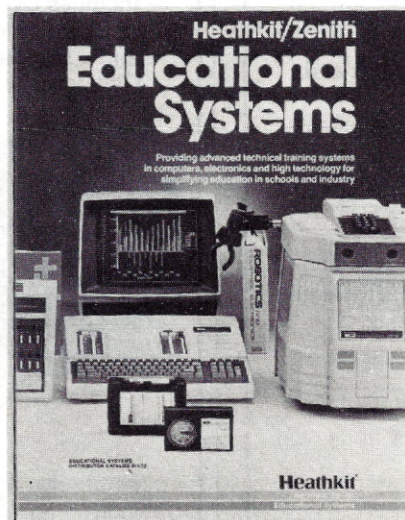
STD-Bus Opto-Sensor Input Card

The Model 4304 16 Opto-Sensor Input card is STD-Bus compatible and has 16 independent opto-sensor inputs (with latch) addressable in two sets of eight. Input circuitry is designed to work directly with the opto-transistor or with uncommitted collector transistor outputs from the sensor without external circuitry. Four of the inputs have Interrupt/Status conditions and are strappable for light-to-dark or dark-to-light operations. Interrupt vectors are strappable in two groups of four, or on a card basis. Polled operation, card address, INTRQ, and INTAK are also priority chained. The 16 Opto-Sensor Input card (\$230 from stock) is manufactured by Technology 80, 658 Mendelssohn Ave. N., Minneapolis, MN 55427, telephone (612) 542-9545.

Circle 41

Heath Education Products

The newest Heath Educational Systems Catalog contains more than 175 technical training aids in computers, electronics, and high technology, for schools and industry. One of Heath's newest products is the EC-1300 CAD Graphics System, complete and ready to run with all necessary hardware, programs, and operating manuals. The EC-1300 features AutoCAD and is a computer-aided drafting and design system that runs on low-cost microcomputers. Another featured product is the ET-18-3 Remote Control Keyboard for the HERO I. The radio-frequency controlled (75 MHz) transmitter and receiver enables both keyboard and teaching operations to be performed from a distance. A serial cassette port permits programmed routines to be



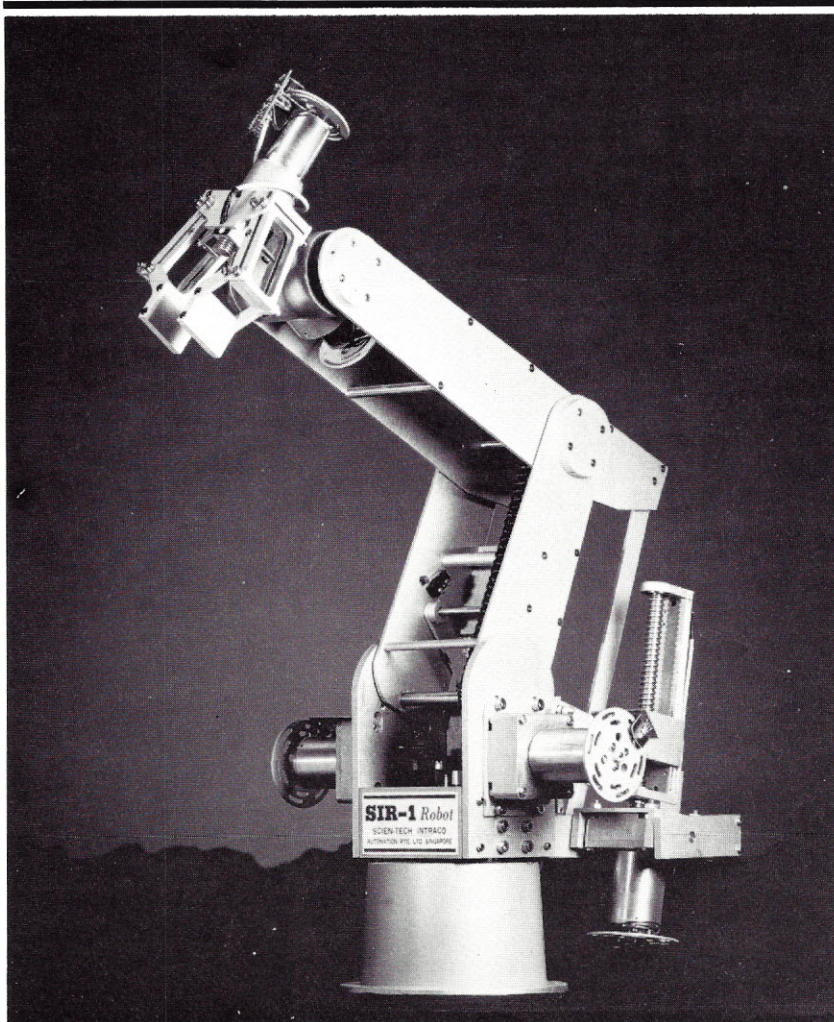
stored on a cassette tape for later use.

The Heath Robot Applications Course covers such subjects as Management Considerations, Vision Systems, Computer-Aided Manufacturing, and nine course experiments. Heath has also introduced the ETW-100 16-bit Learning Computer and Advanced Microprocessor Course. The ETW-100 can be used as a multipurpose trainer or, with the EWA-100-A Accessory Package, can be upgraded to a complete 16-bit disk-based computer.

To receive a free copy of the current catalog, request the Educational Systems Catalog from Heath Company, Dept 570-415, Benton Harbor, MI 49022.

Circle 42

New Products



Singapore Intelligent Robot

Sir-1 is an intelligent multipurpose educational robot used for teaching robotics and simulating industrial robot operations. The articulated Sir-1 robot arm has an open design which leaves the operational parts completely visible. Six DC servomotors and ball screws provide accurate and stable positioning. Each DC servomotor is equipped with an integral optical encoder. A microprocessor-based controller permits simultaneous control of eight DC servomotors and is equipped with many other powerful features such as IO ports for synchronization with surrounding equipment and peripherals, a cassette interface storing control sequences and data, eight-step speed control, user-defined home position, and self-diagnosis. An easy-to-use hand-held teach pendant allows users to program and manipulate the robot without any formal

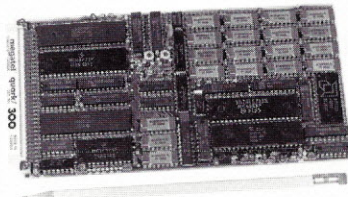
programming knowledge. A set of powerful controller commands enables users to design their own robotic software easily on any computer with an RS-232 serial interface.

The basic system comes with 4 Kbytes of programmable memory which allows up to 6000 program steps. This memory is expandable to 32 Kbytes. Users can closely simulate many real industrial applications by choosing from among a wide range of accessories, including an XY table, rotary table, conveyor, triple-finger gripper, and magnetic hand.

For more information, contact Scien-Tech Intraco, Automation (PTE), Ltd., 456 Alexandra Rd #14-00, NOL Building, Singapore 0511, telephone 2780011, Telex RS 21413, Cable INTRACO SINGAPORE.

Circle 43

Tiny Power



Megatel designers have used PALs, a gate array, and proprietary design techniques to provide a host of features previously unattainable on a single, small board. The basic unit of the Quark family, the Quark/100, has a 6 MHz Z80 processor, boot PROM, 128 or 256 Kbytes of programmable memory, a single- or double-density floppy disk controller for up to four drives, a dual mode alphanumeric or bit-mapped graphics video display controller, full-duplex and simplex RS-232 serial ports, and four parallel ports with 22 I/O lines, five buffered output lines, two 16-bit counter/timers and three control lines—all on a 3.9 by 6.4 in. card. More I/O ports or off-board PROM can be added using the Quark's Peripheral Expansion Bus which brings out data, address, and control lines. The Quark/300 version contains all of the above features plus an ST506 Winchester controller for up to four drives and a video display interface.

All of Megatel's Quarks can run CP/M 2.2 or CP/M Plus. The software package includes a system license, a BIOS, disk and terminal drivers, utilities, source code, and a unique menu-driven installation program which allows the I/O, device drivers, and disk formats to be quickly configured to the user's requirements.

Prices for the Quark/300 range from \$495 to \$895, depending on quantity and amount of memory. An initial development package consisting of a Quark/300, installation software, CP/M, a connector, transition board, and manuals costs \$1145 for CP/M 2.2 and 128K bytes of programmable memory. A 256K byte version with CP/M Plus costs \$1495.

For more information, contact: Megatel Computer Corp, Inc., 1051 Clinton St., Buffalo, NY 14206, telephone (416) 745-7214.

Circle 44

New Products



Microbot Light-Assembly Robot

Microbot, Inc. has introduced a small, low-cost production robot system—the Alpha II—designed to automate simple tasks in the electronics and pharmaceuticals industries. The Alpha II is a more sophisticated, more rugged version of the Microbot Alpha. Up to 227 program steps can be stored in the system's permanent memory. The robot is programmed either through a hand-held device called a teach control, or by an external computer via an RS-232 asynchronous serial interface. Experienced computer users can also program in XYZ coordinates.

An 8-bit 6502A microprocessor in the Microbot Alpha II has 8 Kbytes of EPROM,

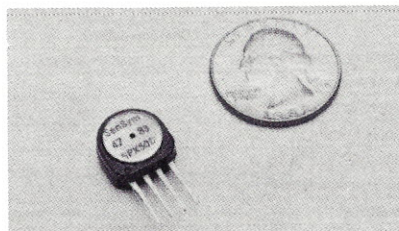
4 Kbytes of EEPROM, and 1 Kbytes of programmable memory. The robot's work cell interface, which contains 18 I/O channels for optically isolated interfaces at factory voltage levels, connects the robot to sensors, actuators, and other peripherals. The arm, which reaches to 18 in. can move at selectable speeds up to a maximum of 51 in. per second and can carry a maximum payload of 3 lbs. Repeatability is ± 0.015 in. at payloads of up to 1.5 lbs.

For more information about the Alpha II, contact Microbot, Inc., 453-H Ravendale Dr., Mountain View, CA 94043, telephone (415) 968-8911.

Circle 45

IC Pressure Sensor

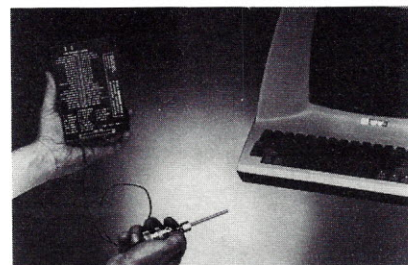
Sensym, Inc. has produced an inexpensive (\$5.00 in quantity) integrated circuit pressure sensor. The SPX50 provides an output voltage proportional to applied pressure. These devices use an ion implanted resistor in an integrated silicon diaphragm to transform pressure and related shear stress into an electrical output. The SPX50A has an integral vacuum reference and an output voltage proportional to absolute pressure. The SPX50D allows application of pressure to either side of the diaphragm and can be used for gauge or differential pressure measurements. The IC sensor element is housed in a compact



plastic package which allows for easy mechanical and electrical interface.

For more information, contact: Sensym, Inc., 1255 Reamwood Ave., Sunnyvale, CA 94086, telephone (408) 744-1500.

Circle 46



ASCII Serial A/D Microsystem

The Passport SDAS-8 from Datal is a compact data acquisition microsystem with serial ASCII connection. The unit accepts eight differential analog channels and transmits them as ASCII serial data to a host computer or terminal using simple command characters. By including both asynchronous RS-232 and isolated current loop serial I/O, the SDAS-8 can be remotely located so that the computer is not exposed to harsh operating conditions.

The 4 by 6 by 0.4 in. steel-cased module includes an internal programmable gain amplifier, software linearization, and a separate cold junction compensation sensor channel for direct connection to thermocouples. SDAS-8 may be connected to the serial port of any computer. Typical applications include computer-controlled industrial test monitors, data logging, or non-processor analog-to-digital scans to any RS-232 terminal or printer. Two-wire remote data acquisition to any distance is easily configured with a user-supplied RS-232 modem.

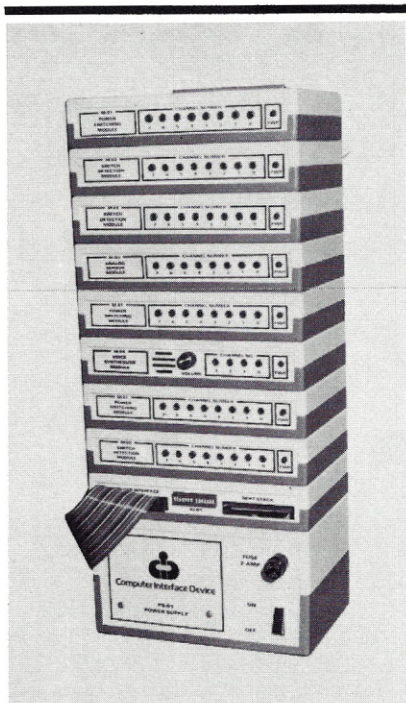
An internal crystal-controlled time-of-day clock value is optionally reported with each scan character string. Analog-to-digital scan transmissions may be automatically started using a second interval clock over user-selectable spans of 1 second to 18 hours. Scan transmissions may also be started remotely from a host computer polling command.

The SDAS-8 internal microprocessor program accepts simple character commands and offers extensive remote reconfiguration. The command-controlled options include decimal or hexadecimal formatting, Celsius to Fahrenheit conversion, and J, K, S, and T thermocouple linearization or DC voltage input.

The Passport SDAS-8 is available from Datal, 11 Cabot Blvd., Mansfield, MA 02048, telephone (617) 339-9341.

Circle 47

New Products



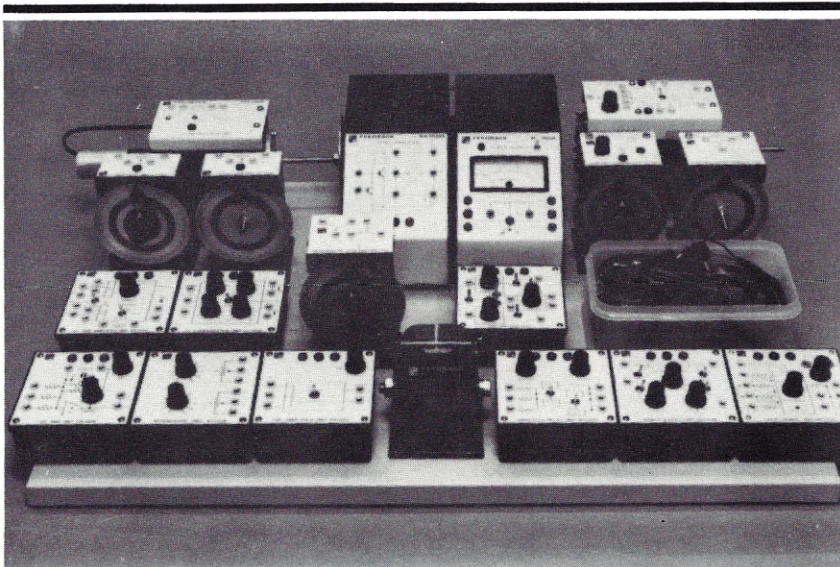
Computer Interface Device

Electronic Systems and Instruments has introduced a series of Cid (Computer Interface Device) modules that link almost any personal computer directly into classroom experiments. Each Cid module is a different but dedicated device supporting a wide range of applications. Cid virtually eliminates the process of manually entering raw data into a computer.

The modular building block concept of snap-together units makes it simple to add on as needs change. Cid modules stack eight high and interface to a computer with a single inexpensive cable. By changing the cable, all modules can be connected to a different computer. Programming is equally simple because no software drivers are required. Users talk directly to modules and sensors. Any computer language (BASIC, assembler, etc.) that accesses a specific memory or port location can be used.

Educators and experimentalists who require computer support for their personal projects and the teaching of scientific fundamentals and who want to minimize their electronic hardware involvement, will find Cid suitable for their needs.

For further information, contact: Electronic Systems and Instruments, Inc., 8301 Castle, Wichita, KS, 67207, telephone (316) 686-5655. Circle 48



Modular Servo System

Feedback, Inc. has announced the availability of the redesigned MS 150 MkII Modular Electromechanical Servo Teaching System, used primarily for the study of automatic control systems. The new MS 150 is particularly well suited for instruction on the university vo-tech, industrial, and military levels. The system incorporates the latest state-of-the-art circuitry, components, and manufacturing techniques.

The modular nature of the MS 150 MkII allows it to be supplied in several kit forms. The DC Modular Servo System MS 150, the basic kit from which all others are derived, permits the individual study and construc-

tion of speed and position controls using DC error signals. The AC Modular Servo System MS 150A is appropriate for more advanced and specialized engineering studies, requiring detailed knowledge of AC carrier systems. The MS 150A is ideal for control and engineering studies in military and aviation schools, as well as colleges and universities with intensive curriculums in aerospace and advanced electronic industries.

For complete information, contact: Feedback, Inc., 620 Springfield Ave., Berkeley Heights, NJ 07922, telephone (800) 526-8783, or (201) 464-5181. Circle 49

Classified Advertising

COMPUTER MOTION CONTROL—Learn the principles by building a flatbed plotter controlled by a Commodore 64 or VIC 20 computer. Plans, programs, manual, etc. \$49.00 Kit including motors \$119.00. Assembled and running \$249.00. Stepper Motor Controller Two motors for the Commodore 64 or Vic 20 with fast machine code program on disc or tape \$75.00 with stepping motor \$99.00. Maxiplot, 839 Seafoam, Houston, TX 77062.

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Here's a robotics idea that grows with you.



Introducing Tutor™, a modular, reconfigurable robotics kit.

The best way to learn about robotics is to build a robot. And after you've built it, you'll probably think of ways to build it better. That's exactly why we designed Tutor.

The Cybot Tutor™ is actually an educational robotics kit — an environment for studying the principles of robotics in detail. It gives you hands-on experience building, programming, and using robots.

Tutor's modularity lets you begin with the basics. Controlling a stepper motor is easy. Add optical encoders for feedback. Tutor's arm gets you into linear and geometric motion control. Add the turret assembly and the Cybot Gripper™ and you're off into complex three dimensional robotics applications.

Going from one experiment to the next is easy with Tutor. For example, a 5-axis robot can be assembled in under 30 minutes!

Even the electronics are modular. Tutor's control electronics use the IEEE-696 bus (S-100). A 16-bit cpu controls Tutor while 8-bit microprocessors control the stepper motors. This lets Tutor move six stepper motors simultaneously. And extra bus slots are available for control or I/O boards that you might want to add.

An RS-232 port lets Tutor communicate with most personal computers. If you can run a serial printer, you can control Tutor.

Some of the best news is Tutor's price. You can get this industrial-grade educational robotics kit for only \$3,395.00.

Here's how to get your hands on Tutor and get into robotics, call:

800-547-4000 Dept. 610

In Oregon, or outside the USA, call:
503-684-3000 Dept. 610

To order direct, send checks or purchase orders to: Cybot, Inc.,
733 7th Ave., Kirkland, WA 98033.

Distributor and Representative inquiries are invited.

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